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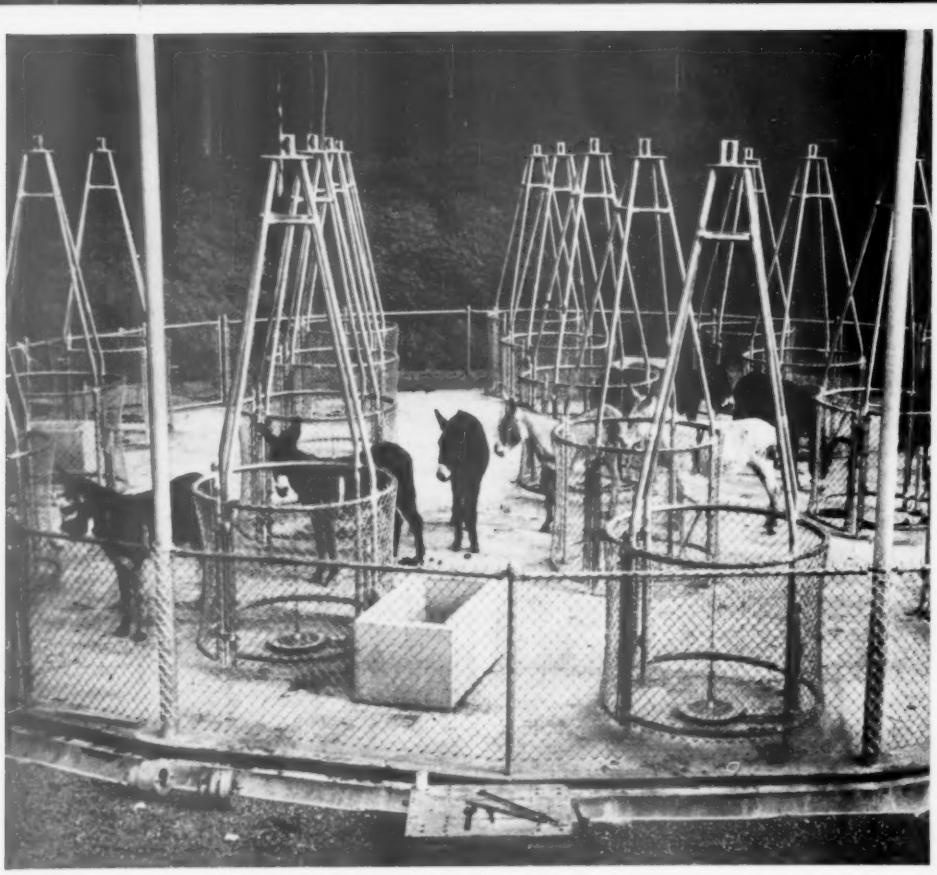

New multicurie exposure field at Oak Ridge designed for whole-body gamma irradiation of large research animals. Radioisotope sources, kept in water-filled cisterns under 19 "derricks" on field, are raised when in use. Photo shows burros in deactivated field (see page 36)

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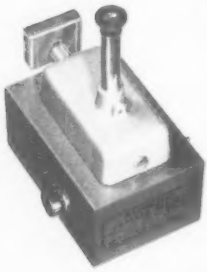
Victoreen Pocket Dosimeters ... For Every Purpose

THE MODEL 287 CHARGER-READER is used with the Model 362 chamber, and operates from 110 volts A.C.



THE MODEL 392 is a battery operated unit for charging and reading the Model 506 and 507 chambers.

A dosimeter is an instrument which measures the total accumulated quantity (dosage) of X or gamma radiation. The reading is in roentgens regardless of exposure time. Pocket dosimeters, sometimes called pocket chambers, are either direct reading or indirect reading. Direct reading pocket chambers have a built-in optical system and electrometer, which permits the wearer to periodically observe the dosage which has accumulated since the chamber was last charged, thus enabling him to retreat from a hazardous area when the dosage approaches the average daily tolerance. Indirect reading dosimeters require a Minometer (charger-reader) to observe the reading. This reading is usually checked at the end of the working day by a competent technician.

MODEL	TYPE	FULL SCALE SENSITIVITY	CONDITIONS
362	Indirect	0.2 r	At or below daily Tolerance Rate
541	Direct	0.2 r	At or above daily Tolerance Rate
547	Direct	5. r	Emergency
548	Direct	50. r	Trained personnel—Emergency
534	Direct	5. and 50. r	Civil defense, etc.
506	Indirect	100. r	Untrained personnel—Emergency
507	Indirect	200. r	Untrained personnel—Emergency

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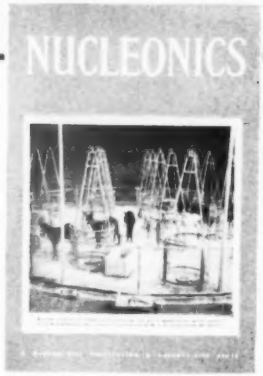

MAY • 1952
Vol. 10, No. 5

Radiation Safety for a Weapons Test... 10

Survey Methods for Fast and High-Energy Neutrons... 14
BURTON J. MOYER

Cyclotron Safeguards... 20
FRANCIS L. BRANNIGAN, HANSON BLATZ, and EDWARD J. KEHOE

Radioactivation Determination of Zirconium in Zr-Hf Mixtures... 24
J. E. HUDGENS, Jr., and H. J. DABAGIAN

1.2-Mev Accelerator at the Australian National University... 28
E. W. TITTERTON

Determination of Geologic Time... 30
RICHARD L. BURLING

A Multicurie Irradiation Site for Exposure of Large Animals to Whole-Body Gamma Irradiation... 36
JAMES L. WILDING, CHARLES S. SIMONS, and JOHN H. RUST

Backscattering of Beta Rays in Windowless G-M Counters... 41
DARLEANE CHRISTIAN, WAYNE W. DUNNING, and DON S. MARTIN, Jr.

Mobile Radiochemical Laboratory... 44
J. KOHL and R. L. NEWACHECK

Performance of Pulsed Photomultipliers... 46
R. F. POST

Observations on Pulse-Height Resolution and Photosensitivity... 51
ROBERT K. SWANK and WARREN L. BUCK

Energy Absorption by Externally Irradiated Liquids—II... 54
STANLEY L. WHITCHER

Cross Sections

Mount, Electronics, and Indicator for Probe Counter... 60
THEODORE FIELDS

Berkeley Cyclotron Oil Difficulties... 61
J. VALE

Chemical Dosimeter for Ionizing Radiations... 62
JOHN W. KANWISHER

Departments

EDITORIAL... 9
BOOKS... 66
NUCLEONIC EVENTS... 72
PRODUCTS AND MATERIALS... 80
LETTERS... 86

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Instruments

- BROWN ELECTROMETER Pages 64-66
- FUNCTION PLOTTER Pages 54-56
- EXTENDED RANGE PRECISION INDICATOR . . . Page 56
- DUPLEX TWO PEN RECORDER Pages 60-61
- NARROW SPAN RECORDERS Pages 57-59
- ElectroniK HIGH SPEED RECORDER . . Pages 62-63

Components

- BROWN CONVERTERS Pages 86-87
- BROWN SERVO AMPLIFIERS Pages 90-95
- BROWN BALANCING MOTORS . . Pages 88-89

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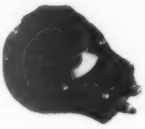

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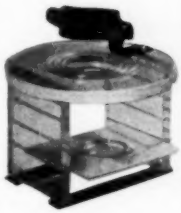

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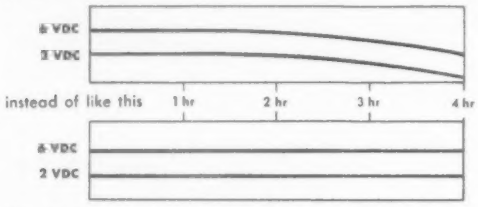

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#3 for bias	2VDC adjustable ±10% at 100 Ma.
Filtering	
#1	1% max.
#2 & 3	0.05% max.
Regulation accuracy	±0.01% against line changes
Time constant	0.1 seconds under most severe line changes

Size: 17 x 12¼ x 17 self contained
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Weight: Approximately 90 pounds

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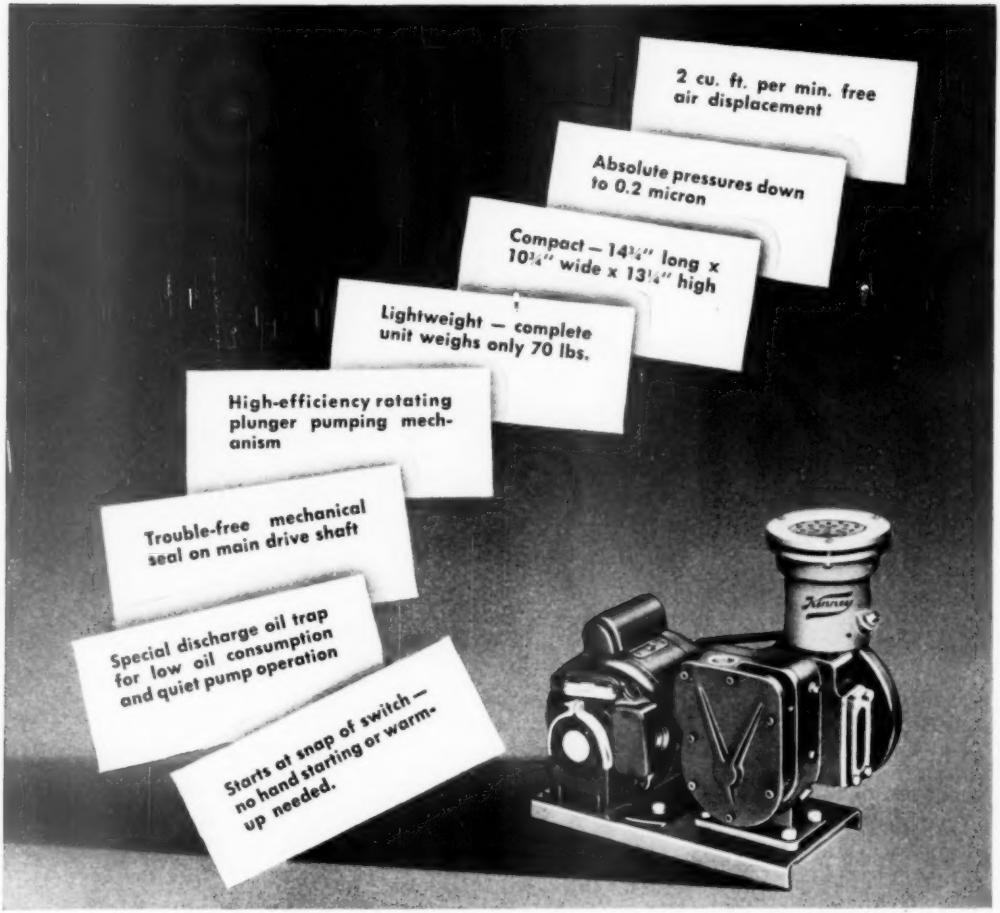
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COLLIMATOR
Geometry: 2.5 × 10-3 at apex.
Resolution: 8° rotation on Crystal Axis reduces count by 50%.
12° rotation on Crystal Axis reduces count by 80%.

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NUCLEONICS

MAY, 1952

Report on a Weapons Test

This is not an editorial in the usual sense of the word. Instead it is a personal report on an atomic explosion.

When I went out to the AEC"s Nevada proving grounds last month to witness a weapons test—my first—I had no idea of what was in store for me. I had seen at least several color films of other tests, I had read descriptions of atomic explosions in books and articles, and I had spoken to many people who had seen them. But, despite all of this, I did not expect to see what I saw.

My immediate reaction to this burst was one of looking at a panorama of great esthetic beauty. I had expected to feel a sensation of horror and awe. Instead I marveled at the magnificent colors—pink, orange, red, white—displayed against a clear, blue sky.

This was a test such as was never before held by this country. The bomb—in the range of 20,000 to 30,000 tons TNT equivalent—was detonated at a height of 3,500 ft. above the ground. Because of this altitude—the Hiroshima and Nagasaki bombs went off at about 2,000 ft.—the usual mushroom associated with atomic bombs did not develop.

Almost instantaneously with the detonation of the bomb, a heat flash hit my face (I was 10 to 11 miles from ground zero). The sensation was similar to one which results from opening the door of a furnace.

A few seconds later I removed my high-density protective glasses and saw a small, cottonlike puff hanging in the air above ground zero completely detached from everything around it. Although the diameter of the puff or cloud was about a mile, I always had the feeling of petiteness and delicacy and softness of texture and color.

As the cloud slowly rose, its temperature dropped and the colors changed from reddish hues to snow white with ice forming on the top. The puff assumed the shape of a doughnut as it drifted upwards, until it soon spread out in amorphous fashion.

Another contrast with what I anticipated was the intensity of the noise from the explosion. I had expected a tremendous roar. Instead, there was a short, sharp crack such as one might get from a sizeable firecracker on the Fourth of July.

In reporting this experience, I have not attempted to present any picture which would permit evaluation of the bomb as a weapon. Although I may have given the impression that it is rather puny, there is no question but that it is becoming an increasingly ferocious weapon.

My reasons for writing about this have been not only to describe an interesting experience, but more important to tell about that which is the purpose for the existence of the atomic energy program. I was singularly impressed with the matter-of-fact manner with which most of the scientists and engineers working at the Nevada proving grounds described their role in the program. As people in this field have been accustomed to dealing with multi-million-dollar research tools, so these men have adjusted themselves to carrying out nuclear detonations in their outdoor laboratory.

The entire weapons test observer program, which covered four days, went off with almost clockwork precision. I feel sure that through it the general public will gain greater understanding of AEC"s problems. The Commission should be complimented on a job well done.

—*J.D.L.*

EXPLOSION of atomic bomb at Yucca Flat set in motion complex monitoring system

Radiation Safety for a Weapons Test

An eyewitness report on the elaborate system used to obtain detailed data on distribution of radioactivity from the atomic explosion on April 22

ATOMIC TEST SITE, YUCCA FLAT, NEVADA—April 22. Within one hour after the detonation of an atomic bomb here this morning, a very elaborate radiation survey operation was set in motion. Monitoring teams started making measurements in the vicinity of "ground zero," in planes up to the radioactive cloud and down at about 50 ft above the ground, and at selected locations on the ground hundreds of miles from ground zero. In addition, 121 stationary monitoring installations at various points beyond 500 miles from the blast centers were set to record data.

This extensive operation has four principal goals: (1) protection of test personnel and populated areas, (2) safeguarding sensitive industries, (3) obtaining basic meteorological data, and (4) collecting nuclear weapons effect data.

The bomb exploded this morning was slightly larger than "nominal"—equivalent to more than 20,000 tons of TNT. It was dropped by a B-50 from an altitude of 30,000 ft and was detonated 3,500 ft above the ground. For such an air burst, the following conditions held.

1. Resultant Nuclear Radiation. This consisted of two types—initial and residual. The former is made up of gammas and neutrons, the latter of alphas, betas and gammas. The dosage from initial gammas varies (for a nominal bomb) from about 10,000 roentgens at a distance of 2,100 ft from the explosion to less than 2 roentgens at 9,000 ft. Initial neutrons which would have a lethal effect have a range of about ½ mile from the explosion. Residual radiation comes from fission products and unexploded fissionable material. The total gamma activity of the fission products varies from 820,000 megacuries at the end of one minute to 2.3 megacuries at the end of one month.

2. Radioactive Contamination. Past experience has shown that in the case of one nominal bomb, 0.02% of the fission products were left on the ground within a radius of 2,000 ft from ground zero. As far as a radioactive cloud is concerned, the crew of a plane flying at 300 mph through a 6,200-ft diameter cloud at 15,000 ft would receive more than 140,000 roentgens per hour 90 sec after the explosion. Ten minutes later, in a 14,000-ft diameter cloud, the same crew would receive more than 3,000 roentgens per hour at an altitude of 40,000 ft.

The function of the monitoring teams was to obtain data in the above two categories. To carry out this function, work was divided into three zones: (1) within 200 miles of ground zero, (2) from 200 to 500 miles out, and (3) beyond 500 miles.

Jurisdiction for radiation safety within the area up to 200 miles out falls under the local test operations

1 At 121 WEATHER BUREAU stations, samples are collected that will be used to determine amount of radioactivity in air. Circles are 500 miles apart

TO SEE WHAT HAPPENS TO SAMPLES, TURN PAGE

staff and is headed by Lt. Col. J. B. Hartgering. With a 180-man group, his responsibility is to assure safety of test personnel and the nearby populace.

Within 200 Miles

Shortly after the bomb explosion, a small plane was sent in around ground zero to survey the area at about 50 feet above the ground. Very shortly thereafter, the plane flashed the "all-safe" signal, and four teams in Jeeps moved in with 0-to-50-roentgen gamma ion chambers to carry out a detailed survey. After this check was completed in about an hour, other test personnel were permitted to enter the area.

Several hours after the blast, 11 planes took to the air to do cloud sampling, cloud tracking and terrain surveying. The sampling operation is done by planes which circle through the radioactivity cloud out as far as 600 miles. Data are obtained to determine the safety of airways crossed by the cloud and to provide means for evaluating weapon effects. Filter-paper boxes are attached to the wings of the planes for collecting the weapons data, which are evaluated at Los Alamos.

The terrain survey is carried out by planes flying 50 ft above the ground. The principal instrument they use is an ion chamber which receives its samples through a 6-ft-long tube attached to the outside of the plane. This instrument can differentiate between activity on the surface of the ground and that in the air at the level of the plane.

200–500 Miles

In this area, about six mobile teams under Merril Eisenbud, Director, Health and Safety Division, AEC New York Operations Office, use air samplers to make fall-out measurements on the ground under the radioactivity cloud. Samples are collected for periods of 20–120 minutes during the 48 hours after the explosion.

Beyond 500 Miles

The New York Operations Office also has responsibility here. As shown on the map on this page, 121 Weather Bureau stations have been set up as stationary sample collection points. In addition to assisting the AEC, the Weather Bureau, under H. Wexler, Chief of Research, has effectively had a radiotracer means of getting data on the motion of large masses of air at varying altitudes. Besides providing meterological data, this system is used as a guide for industries which might be sensitive to small amounts of radiation.

The equipment used was specially designed by and under the supervision of H. D. Levine and H. J. Di Giovanni. The complete setup is shown on the next two pages. —*J.D.L.*

2 ONE OF TWO methods for collecting radioactive dust at Weather Bureau stations. Samples are collected for 24 hrs on 1-ft² gummed paper held on 3-ft high stands. Those shown are on roof of AEC's N. Y. Operations Office building

3 AIR SAMPLER used at many of the Weather Bureau stations (See map on p. 11). An air flow of 40 ft³/min is maintained through 4-in. diameter filter paper. In use, air sampler is placed in box to protect it from elements

5 GIRL in foreground folds sample paper into crucible for ashing in furnace

6 CRUCIBLES containing samples are placed in oxygen-fed furnace for ashing

7 GIRL on left in Fig. 5 grinds ashes places them in planchet

10 DATA from counting room is recorded on cards, and edges of cards punched to give data. Sorting of cards is done with ice-pick tool, utilizing punched holes

DATA SHEET

STATION: USWB NEW YORK, N.Y. (LAGUARDIA FIELD)

A. TYPE OF SAMPLE (CIRCLE ONE NUMBER)	B. WEATHER TYPE (CIRCLE ONE NUMBER)	C. PREC (CIRCLE O
1. GUMMED PAPER	1. CLEAR	1. TRACE
2. HIGH VOLUME SAMPLE	2. FOG	
3. AEROTEC	3. CLOUDY	
4. CASCADE	4. RAIN	
5. OTHER	5. SHOWERS	

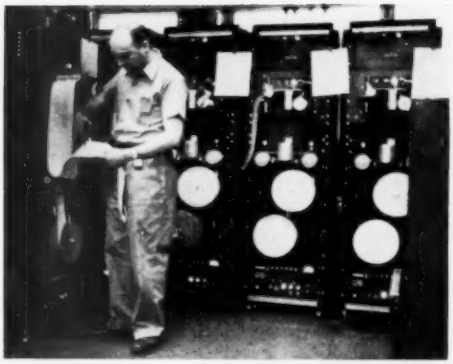
AIR SAMPLERS ONLY — STARTING RATE

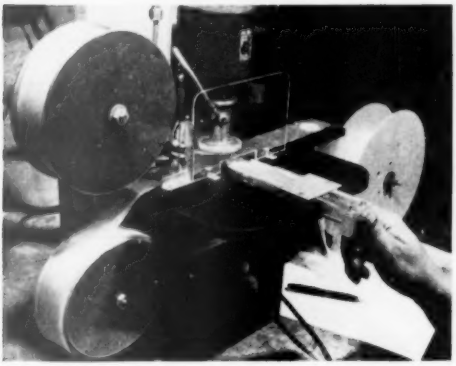
08301 CE BEL 08302

	1.	2.
COUNTED — DAY	10	10
— HOUR		
TOTAL COUNT		
MINUTES		
NET	2	0
SAMPLE		
UNCORR	10	0
EXT		

11 DATA CARD from Laguardia Field for background conditions. Gummed-paper sample was obtained when weather was clear, no precipitation, 8–12 mph wind in northerly direction

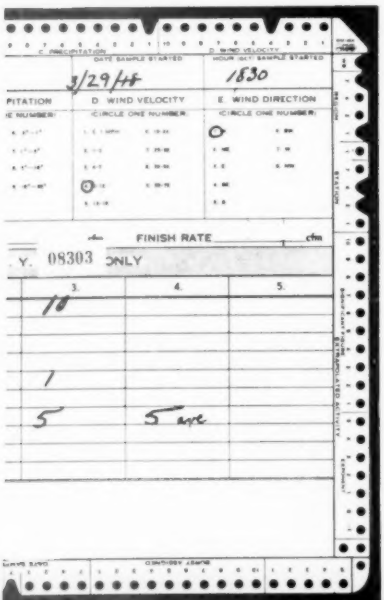
4 SAMPLES come into special post office box at AEC's N. Y. office. Girl places duplicate numbers on each sample, on planchet and on data card. From 400 to 600 samples have been counted daily since operation started March 20





8 NUMBERED PLANCHETS are sealed between two strips of polyvinyl tape. Each 25th planchet in a 100-sample roll is left empty as a control. Spacing of planchets is 8 in.

9 SAMPLE ROLLS are placed on automatic counting apparatus. Each sample is counted for 20 minutes or 640 counts, whichever comes first. TOP picture shows complete apparatus, with each cabinet containing, from floor up, an El-tronics scaler, sample transport mechanism with specially designed Anton G-M tube, and Streeter-Amet printing recorder that records sample position on tape, count, and counting time. Clip boards hold sheets relating printed numbers to planchet numbers. MIDDLE picture shows how guide rollers shield sample being counted from other samples. BOTTOM picture is closeup of counter and tube. Starting voltage of tube is 650 volts; minimum plateau length, 100 volts; maximum relative plateau slope, 15%/100 volts; max. background, 15 cpm



Survey Methods for Fast and High-Energy Neutrons

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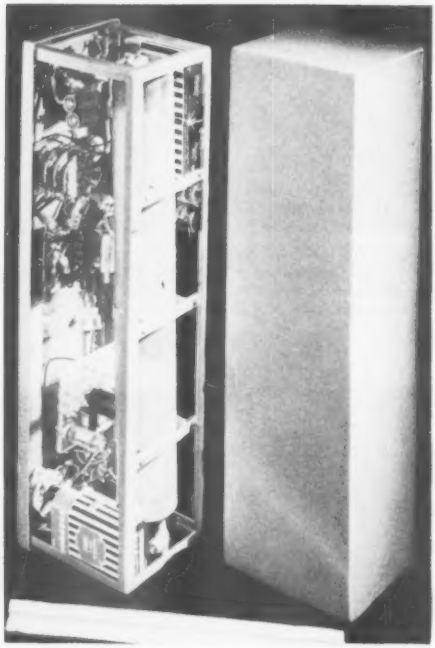

FIG. 1. Rear view of fast-neutron proportional counter

For the determination of neutron hazards, the energy spectrum is divided into three parts. Discussed here are eight methods for surveying neutrons in the ranges from 0.3 Mev to 15 Mev, and from 15 Mev up

NEUTRONS PRESENT in large numbers in the vicinity of particle accelerators and reactors present a considerable hazard to personnel working in the area. To protect such personnel, adequate surveys must be made to determine the intensity distribution of the neutrons.

For the purpose of choosing instruments to make such surveys, it is best to consider the neutron-energy spectrum in three distinct portions. Then the best measurement method for the particular energy region can be chosen.

Survey methods for both the thermal and near-thermal region were discussed last month (*1*). This article will be concerned with the two higher energy regions. In the first are fast neutrons, whose energies are from the capture-resonance region, 0.3 Mev, up to about 15 Mev. Two survey instruments that can be used in this region are shown in Figs. 1 and 2. In the second region are high-energy neutrons, with energies from 15–20 Mev, and up.

Fast-Neutron Fields

The concern of this section is with neutrons extending in energy from a few tenths of an Mev to 15 or 20 Mev. Within this region the predominant process by which energy is delivered to a biological medium is the recoil of protons from collisions of the neutrons with hydrogen. That this is true may readily be ascertained by reference to the values and behavior of the n-p cross section and of the collision cross sections for C, O, and N in this energy region, bearing in mind the important fact that in collision with hydrogen the neutron imparts, on the average, half of its energy to the recoil proton, whereas in collisions with C and O nuclei the neutron loses typically only 0.14 and 0.11 of its energy, respectively.

It is obvious then, that most fast-neutron measurements are made by taking advantage of the simple and known characteristics of the n-p colli-

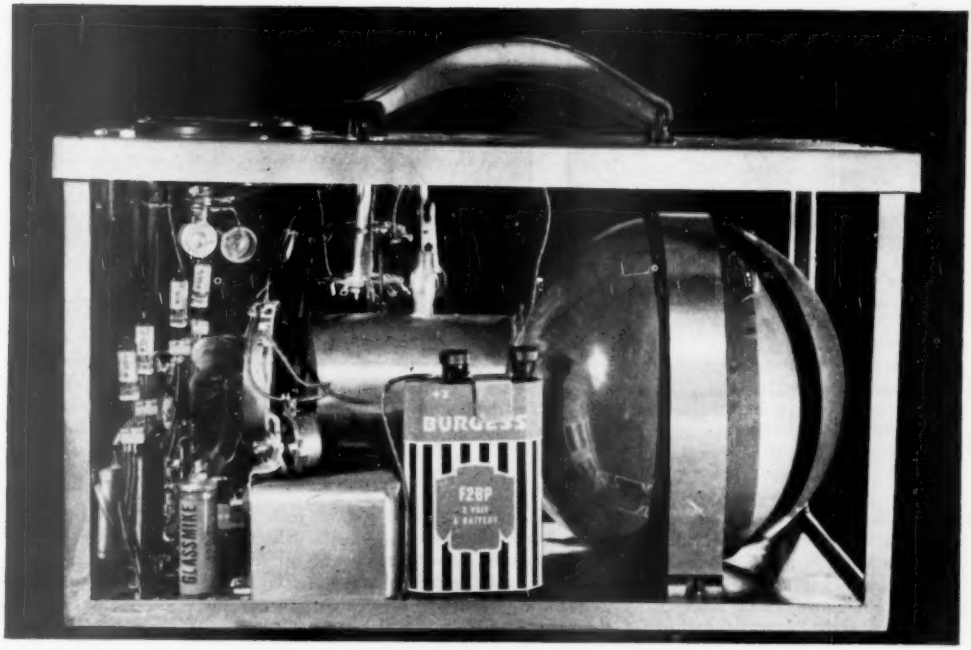

FIG. 2. Fast-neutron scintillation counter having spherical geometry

sion. Within this energy region the kinematics are those of a simple, elastic billiard-ball collision, i.e., there is spherical symmetry in the center-of-mass system. In Fig. 3 are displayed the values of σ_{np} vs neutron energy, and the range of a recoil proton in CH_2 vs its energy. Also shown, because of its subsequent use, is a plot of $\sigma_{np} \times R_p$.

The damage to a biological medium will depend fundamentally upon the product of σ_{np} and neutron energy, since in this energy region essentially all recoil protons remain within the medium and deliver all their energy thereto. Because of the manner in which σ_{np} decreases with neutron energy, the product $E\sigma_{np}$ is nearly constant over the fast region. The relative biological effectiveness of the neutrons in this region does not have pronounced dependence upon energy.

Of the survey methods described below, each has its own restricted field of validity. No one technique answers all questions about fast-neutron radiation. Consequently, it is necessary to give careful attention to the restrictions placed upon the conditions in energy, direction, etc. for which a given method is validly interpretable.

Nuclear-track film. Since the tracks of recoil protons in photographic emulsions are identifiable upon development, it is possible in principle, if the hydrogen content of the emulsion is known, to evaluate an integrated neutron exposure by counting the number and lengths of such tracks per unit volume of emulsion. The careful work of Cheka (*2*) on this technique for the fast neutrons associated with a pile has been reported and applied in some situations.

The method suffers from the paucity of tracks from exposures within the "permissible" range, there being only about one track per two or three microscopic fields of view for a week's tolerance exposure (0.03 rep of fast neutrons). Thus the measurement of typical personnel exposures is tedious and fraught with large statistical errors. In addition there are the important problems of control of the water content of the emulsion, of processing, and of the effects of fading of the latent image, all of which are discussed by Cheka (*2*).

Energy-insensitive counter, substitution method. A counter which detects neutrons, all coming essentially from a given direction, with an efficiency which is quite independent of energy up to 5 to 10 Mev has been developed and described by Hanson and McKibben (*3*). Since biological damage is not strongly dependent upon fast-neutron energy, this type of instrument is frequently useful, providing the neutrons are nearly unidirectional and within proper energy limits.

When knowledge is desired about the fast-neutron flux coming directly from an accelerator target, or from an aperture in shielding, this type of detector (the so-called "long counter") is aimed at the source and the counting rate observed. Subsequently the production of neutrons is stopped, and a Ra-Be or Po-Be source of known strength is substituted in or near the target position while a new counting rate is observed. Because of the energy insensitivity of the long counter, these rates directly compare the fast-

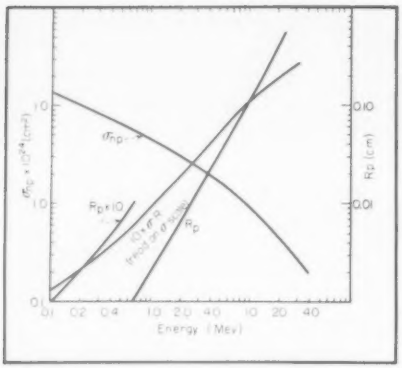

FIG. 3. Plots of np cross section vs neutron energy, proton range vs energy for $(CH_2)_n$ of density 0.95 gm/cm², and of the product of cross section and range

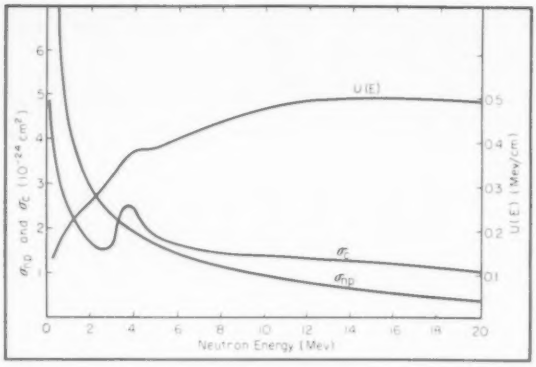

FIG. 4. Plots of hydrogen and carbon scattering cross sections. Also plotted is the function $U(E)$ for $(CH_2)_n$ of density 0.95 gm/cm²

neutron flux densities in the two cases. A known Ra-Be source placed at a known distance on the extended axis of the counter allows an approximately absolute calibration to be made, if precautions about backscattering are observed.

Balanced-chamber. In a manner similar to that used for slow neutrons (*1*) a difference-current technique may be employed for fast neutrons. One chamber contains argon, and is relatively insensitive to the neutrons; the other contains methane, and develops a considerable ionization current from hydrogen recoils. Pressures are adjusted to give equal sensitivities for radium-gamma fields. A useful analysis of this method is given by Gamertsfelder (*4*).

The method has no directional requirements, but the absolute calibration of the neutron response is difficult. Since for even a few Mev energy the proton ranges are comparable to chamber dimensions, the wall effects are not easy to evaluate. Unless very high pressures are employed, the sensitivity decreases pronouncedly with neutron energy above 2 or 3 Mev, and a knowledge of the neutron energy spectrum is essential to an evaluation of exposure rate.

In experience with this type of instrument in the radiation field outside a cyclotron shield, it has been found that the contribution of ionization current by the neutron effects is small compared to that from gamma effects, and is thus difficult to evaluate well. Also, the absolute magnitude of the difference current is undesirably small unless pressures of a few atmospheres are employed which introduce inconvenience in a portable instrument.

The Bragg-Gray Principle (*5*). The "tissue-equivalent" ionization chambers of Rossi and Failla have been discussed (*1*); it was pointed out that it is not possible with them alone to distinguish neutron-produced ionization from gamma-produced ionization, and that this distinction is important because of the different relative biological effectiveness.

Hurst (*6*) describes the means of rejecting the secondary electron ionization by the expedient of biased proportional counting in an approximately tissue-equivalent gas counter with hydrogenous walls. Actually the gas was CH_4, and the wall material $(CH_2)_n$. Ideally the gas amplification and electronic amplification of the pulses magnify the energy-loss events due to the recoil particles in the gas, and the output pulses are integrated into a current which is then proportional to the rate of energy absorption in the gas. This in turn is related to energy absorption in the wall material ("tissue") by knowledge of the counter volume, and the stopping-power ratio and density ratio for the counter gas and wall material.

By adjusting the bias level properly, only those pulses which are above the maximum size produced by secondary electrons will be admitted to the pulse-integrating circuit. Thus only recoil proton pulses will be recorded, and, unavoidably, the smaller of these will be rejected. If amplifications are uniform and known, a calculation of energy absorption rate in terms of integrated pulse current may be made.

Consider then such a proportional counter, with hydrogenous walls and gas of essentially the same hydrogen content per gram, and of reasonably identical stopping powers (on a gm/cm² basis). The wall thickness is to be at least as great as the range of the most energetic recoil protons, but not thick enough to produce appreciable attenuation of the fast neutrons, and the over-all dimensions and location of the chamber relative to the neutron source are to be such that the neutron field intensity throughout is constant. Under such conditions, the mean density of ionization events is uniform throughout the counter volume, and is, in fact, the same as if the solid walls were replaced by counter gas extending in any direction at least as far as the most energetic protons from that direction would travel (assuming also that the uniformity of field extends that far).

Consequently the ionization events within the chamber are representative of those within the gas without solid walls, and the energy absorption per unit volume is simply proportional to density. The energy absorption per gram is thus independent of density and will be equal to the absorption per gram in the chemically similar wall material. So, if the energy absorption rate in ergs/gm-sec for the wall mate-

rial is W, the metered output pulse current in amperes is

$$I = (3.1 \times 10^{-9}) A V \rho_g W$$

where 0.51×10^{-10} ergs per ion pair has been assumed, and where A is the over-all charge amplification of an ionization event due to both gas and electronic amplification, V is the counting volume, and ρ_g is the gas density.

Thus, if a tolerable fast-neutron exposure rate were stated as 0.03 rep/week, to be accumulated on a 48-hr/week basis, the energy absorption rate on the basis of 95 ergs/gm per rep would be

$$W = 1.65 \times 10^{-5} \text{ ergs/gm-sec}$$

and the output current per cubic centimeter of counting volume, with a methane pressure of one atmosphere, would be

$$I_1 = (3.4 \times 10^{-17}) A \text{ amperes/cm}^3$$

A volume of 50 cm³ and a total amplification of 10^4 would produce a current readily measurable by simple electrometer circuits. The counting volume must be kept rather small so that the Compton-electron path lengths, whose pulses must determine the minimum pulse size accepted, will not encroach too much on the pulse distribution from recoil protons.

It is a prime requirement that the gas amplification is known and is uniform throughout the counting volume. Special counter-end configurations and guard-ring systems have been devised (7) for approximating this condition. The necessity of biasing out the electron-produced pulses causes a failure to measure the contribution of energy dissipation from protons producing pulses below this level, and the seriousness of this will depend upon the neutron spectrum.

Possibly it is worthwhile to point out that if the neutron spectrum is sufficiently well known to allow an estimation of a mean value for $\sigma_{np}(E) \times E$, the actual neutron flux may be estimated. This follows from the fact that the energy absorbed per gram of the gas due to hydrogen collisions is

$$W_H = \frac{N_H}{\rho_g} \int_0^{E_{max}} \phi(E) \sigma_{np}(E) \times (E/2)\, dE \text{ ergs/gm-sec}$$

This assumes that a neutron makes only one collision, at most, in the counter gas or wall, which is a good assumption for fast neutrons and counters of typical size. In this equation, N_H = hydrogen atoms/cm³ of gas; ρ_g = gas density in gm/cm³; $\phi(E)$ = flux density per unit range of energy, in n/cm²-sec-erg; and $\sigma_{np}(E)$ = total n-p cross section for neutron energy E. The average energy transfer in the n-p collision is considered to be $E/2$.

The corresponding expression for the collisions with carbon nuclei is

$$W_C = \frac{N_C}{\rho_g} \int_0^{E_{max}} \phi(E) \sigma_C(E) \times \left(\frac{2M}{(M+1)^2} E\right) dE$$

where $M = 12$ is the relative mass of the carbon nucleus.

Plotted in Fig. 4 are curves of $\sigma_{np}(E)$, $\sigma_C(E)$, and of the quantity

$$U(E) = N_H \sigma_{np}(E)\,(E/2) + N_C \sigma_C(E) \left(\frac{2M}{(M+1)^2} E\right)$$

for a CH_2 medium. This last quantity is proportional to the energy absorption rate per unit neutron flux density at the various energies.

If the spectrum is known with enough confidence to estimate average values $\overline{\sigma_{np}E}$ and $\overline{\sigma_C E}$, the total energy absorption is

$$W_H + W_C = \frac{1}{\rho_g} \left\{ \frac{N_H}{2} \overline{\sigma_{np}E} + \frac{2MN_C}{(M+1)^2} \overline{\sigma_C E} \right\} \int_0^{E_{max}} \phi(E)\, dE$$

The integral is of course the total neutron flux density. The bias to eliminate electron pulses prevents an actual value of zero for the lower limit.

Directional count-rate meter for "tissue dose." By judicious construction of the end wall of a cylindrical proportional counter, Hurst and Ritchie (8) have succeeded in producing a counting-rate response for a unidirectional neutron flux whose energy dependence closely approximates the function $U(E)$ for a tissue-equivalent medium. It is very similar to the $U(E)$ plotted in Fig. 4 for CH_2. Tests in monoenergetic, directional neutron fluxes have substantiated the calculations for their counter, but it must be noted that it is valid only for a unidirectional flux normal to the special end wall. The tissue dose it measures is that due to the first collisions of the incident neutrons; thus it applies to a region of the order of one mean free path in depth.

Fast-neutron energy-flux density. Evaluation of neutron flux densities for monoenergetic neutrons is relatively straightforward (7), but in survey work for radiation protection purposes such spectra do not typically exist. It is still quite possible, however, to measure the energy flow per square centimeter per second carried by the fast neutrons. Then if the spectrum is known sufficiently well to estimate an effective mean energy, the numerical integral flux density may be approximated. This technique has been developed by Mather, Moyer, Redmond, and Thompson (9) at the University of California Radiation Laboratory.

The analysis of the energy-flux counter proceeds in five steps:

1. Consider a plane sheet of hydrogenous material of thickness s (Fig. 5) immersed in an isotropic flux of neutrons of energy E. From any volume element, recoil protons will originate with equal probability in any direction, and with equal probability in energy up to the maximum possible value of E. The number of protons produced in dV at depth x which will emerge with sufficient residual range to be detected may be shown (9) to be

$$dF(x,E) = \frac{1}{2} \phi(E) \sigma_{np}(E) N_H\, dV \times \int_{\epsilon_c}^{1} \left(1 - \frac{x}{R(\epsilon) - r}\right) d\epsilon \quad (1)$$

where $\epsilon = E_p/E$ = fractional energy delivered to a recoil proton, ϵ_c = minimum fractional energy for emergence from depth x, $R(\epsilon)$ = range in the hydrogenous material of a proton with fractional energy ϵ, and r = residual range required upon emergence to allow detection. The other symbols have the same meaning as in the section on the Bragg-Gray principle.

2. If now, $R(\epsilon)$ is approximated by $R(E)\epsilon^{2.2}$, where $R(E)$ is the proton range for $\epsilon = 1$; and if, to begin with, the required residual range, r, is set equal to zero, Eq. 1 may be integrated to yield

$$dF(x,E) = \frac{1}{2} \phi(E) \sigma_{np}(E) \left\{ 1 + \frac{2x}{R(E)} - 3\left(\frac{x}{R(E)}\right)^{2/3} \right\} N_H\, dV \quad (2)$$

This last approximation of $r = 0$ is not employed in more precise calculations (9).

3. The contributions from all depths, x, are now to be summed. Denote volume element dV by $A\,dx$, where A is a plane area parallel to the surface. Then by integration over x, the results

may be obtained for the cases $s \geq R(E)$ and $s < R(E)$.

Case 1, $S \geq R(E)$

$$F(E) = \frac{1}{2}\phi(E)\sigma_{np}(E)N_H A \times \int_0^{R(E)} \left\{1 + \frac{2x}{R(E)} - 3\left(\frac{x}{R(E)}\right)^{2}\right\} dx = \frac{1}{10}N_H A\,\phi(E)\sigma_{np}(E)R(E) \quad (3)$$

Case 2, $S < R(E)$

$$F(E,S) = \frac{1}{2}\phi(E)\sigma_{np}(E)N_H A \times \int_0^{S} \left\{1 + \frac{2x}{R} - 3\left(\frac{x}{R}\right)^{2}\right\} dx = \frac{1}{2}N_H A\phi(E)\sigma_{np}(E)R(E) \times \left\{\frac{S}{R} + \frac{S^2}{R^2} - \frac{9}{5}\left(\frac{S}{R}\right)^{2.5}\right\} \quad (4)$$

Equation 3 or 4 will give the number of protons emerging each second from one face of the sheet, having been produced within the parallelepiped volume AS by neutrons of energy E.

4. The total number of protons emerging per second is to be obtained by integrating over the energy spectrum. This integration is divided into two parts: (a) Energy interval from $E = 0$ to $E = E_S$, where E_S is the energy required to give range S in the sheet material, and (b) Energy interval from E_S to infinity, or to E_{max} for the spectrum of the neutrons. Thus, if every proton which emerges can be counted, the counting rate arising from area A will be

$$C = \int_0^{E_S} F(E)\,dE + \int_{E_S}^{E_{max}} F(E,S)\,dE \quad (5)$$

where $F(E)$ and $F(E,S)$ are Eqs. 3 and 4, respectively.

In many instances $S > R(E_{max})$, so that only the first term of Eq. 5 is involved. (For example, the range of a 15-Mev proton in polyethylene is only 0.24 cm, or $^3/_{32}$ in., which would be quite reasonable a wall thickness.) Advantage is now taken of the fact evident from Fig. 3 that, over a wide range of energies in this region, the product $\sigma_{np}(E)R(E)$ is very nearly proportional to E. From less than 0.1 Mev up to 20 Mev the approximation

$$\sigma R = (1.0 \times 10^{-26})E \quad (6)$$

with E expressed in Mev, and the product σR in cm^2, is nowhere in error by more than 15%.

Thus for a sheet whose thickness is greater than $R(E_{max})$, so that only the first integral of Eq. 5 is required, C becomes, in view of Eqs. 3 and 6

$$C = (1.0 \times 10^{-27})N_H A \times \int_0^{E_{max}} \phi(E)\,E\,dE \text{ cps} \quad (7)$$

The integral appearing here gives the total energy flux density carried by fast neutrons. Corrections to this somewhat oversimplified discussion are mentioned in the next step.

5. The sheet of CH_2 is now bent into a cylinder whose radius is large compared with S, and is very lightly graphited with aquadag to provide conduction. It is then made to serve as the cathode of a proportional counter filled with argon plus a small percentage of CO_2.

The refinements to the foregoing calculation involve the following items:

A. Treatment of the problem with r not zero, i.e., with a specified residual range required for detection.

B. Effects of argon and carbon recoils.

C. Geometrical effect of bending the flat sheet into a cylinder.

D. Inclusion of neutron energies for which $R(E) > S$, i.e., the use of both terms of Eq. 5.

The results of such a calculation are displayed for various CH_2 sheet thicknesses in Fig. 6, in which the ordinate is efficiency in counts per unit area per unit flux density of neutrons in unit energy interval at E. It is evident that below 1 Mev the requirement of a residual range which will provide as much as a 0.2-Mev energy loss in the counter gas reduces the efficiency markedly below proportionality to neutron energy. However, 0.2 Mev is possibly a more stringent requirement than is necessary if proper counter design keeps electron path lengths short. Actually the curves of Fig. 4 do not contain corrections B and C, and the contribution of argon for a typical counter is indicated separately. Correction C can be estimated to be small for a typical counter diameter of 5 cm, though its effects at the higher energy end begin to be appreciable.

From Fig. 6 it is seen that if the spectral region of interest lies between 0.8 Mev and nearly 20 Mev, a $^1/_8$-in.-wall counter has a sensitivity essentially proportional to energy, and the simple relationship of Eq. 7 may be used. If values of residual proton range, r, smaller than 0.2 Mev equivalent are possible, the lower energy limit of this proportional region is moved downward as is indicated by the ideal curve for $r = 0$.

In Figs. 1 and 2 are shown two distinctly different types of survey units employing the foregoing principles. The first is a polyethylene-wall proportional counter. The second is a polyethylene spherical shell whose inner surface is coated with a phosphor; recoil protons produce scintillations which are viewed with an end-window photomultiplier tube through a suitable aperture. In each case the primary pulses, after amplification and discrimination, trigger a one-shot multivibrator whose output is integrated into a counting-rate reading.

The spherical scintillation counter has certain advantages. The fast neutron radiation outside the shielding of an accelerator is not completely isotropic, and the spherical geometry removes the requirement of isotropy. (However, it should be mentioned that the requirement of isotropy for the cylindrical proportional counter is certainly not stringent, as it would be for the flat sheet.) Another advantage is the possibility that electron pulses can be more favorably rejected because of their small energy loss in the very thin layer of phosphor, thus allowing the use of a small value for r, the residual proton range for detection.

As an example, with the spherical counter shown, the discriminator was set so as to reject all counts from a radium-gamma field of 30 mr/hr. The counter was then tested with a known Po-Be source producing an energy flux calculated from the Po-Be spectrum. The experimental result was 1 cps for 15.9 Mev/cm^2-sec. The calculated counting sensitivity from Eq. 7 was 1 cps for 13.9 Mev/cm^2-sec. Corrections for inefficiencies at low energies, as indicated in Fig. 6, would tend to bring the numbers closer, but agreement to better than 15% can be considered fair for survey counters. This degree of agreement has consistently been found with both proportional counters and scintillation counters.

High-Energy Neutron Fluxes

Accelerators of nuclear particles in the hundreds-of-Mev region produce large numbers of neutrons extending in energy up to the primary energy of the nucleons accelerated. Because of the

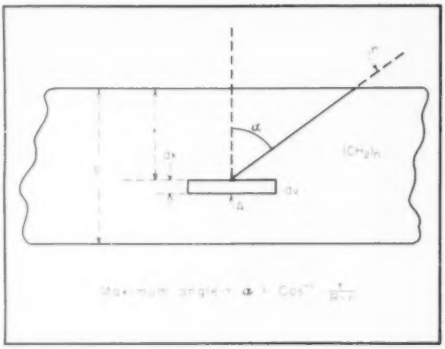

FIG. 5. Diagram for analysis of protons emerging from sheet of $(CH_2)_n$

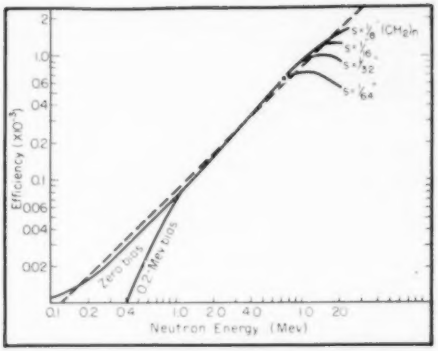

FIG. 6. Calculated counter efficiency as a function of neutron energy for various wall thicknesses. Dotted line is $(dC/dE)(1/N_H A \phi(E)$ from Eq. 7

great penetration of such neutrons through shielding matter, and because nuclear cross sections decrease monotonically with neutron energy in this region, the neutron radiation escaping from the outer surface of a thick shield wall will consist of the equilibrium secondary neutrons accompanying the penetrating primary component. After the initial transition region, in which the soft components of the primary radiation are rapidly absorbed, and the secondary neutron radiation is developed into equilibrium with the high-energy components of the primary, the ensuing attenuation is controlled by the penetration of these high-energy primary components.

In consequence of this, the neutron spectrum external to a thick concrete shield should decrease monotonically from the thermal-energy spectral intensity to that at higher energy. If one can then make flux measurements at thermal energies, in the fast region, and at high energy, one can roughly delineate the total picture. Because of the low flux of the high-energy component when its equilibrium secondary radiation is within tolerance bounds, and because of its relatively low interaction cross section with matter, this high-energy component is difficult to measure on a survey basis.

Nuclear stars and recoils. The ejection of fast, charged nuclear particles from nuclei struck by high-energy neutrons produce characteristic stars in photographic emulsions. Knowledge of the nuclear composition of the emulsion, and estimates of cross sections for star production in various elements allow approximate flux evaluations if cross sections are not strongly energy dependent.

As an example of such a procedure the following data pertain to a certain situation near the 184-in. cyclotron.

The composite inelastic collision cross section per cubic centimeter of the emulsion was calculated from the known chemical constituents, and from the total nuclear collision cross sections at 90 Mev (assumed in this case to be an effective energy for the high-energy components outside the shielding). At these energies, inelastic collision cross sections are almost exactly one half the total cross sections. Thus

$$\frac{1}{2}\Sigma\sigma_i N_i = 0.041 \text{ cm}^2 \text{ per cm}^3 \text{ of emulsion}$$

It was assumed that about $\frac{1}{3}$ of this composite inelastic cross section resulted in identifiable stars.

The star production rate was found to be 0.3 stars/mm³ per hour, or 0.08/cm³-sec.

Thus the high-energy neutron flux density was estimated to be

$$\phi = \frac{0.08}{(\frac{1}{3})(0.041)} \simeq 6 \text{ n/cm}^2\text{-sec}$$

Bismuth fission counter. Fission of the Bi nucleus by high-energy neutrons sets in at about 50 Mev, and appears to rise regularly in its cross section up to over 300 Mev. A design of a Bi fission counting chamber by Wiegand (*10*) has served as a prototype for those employed in survey work.

The fission cross section of Bi under neutron bombardment has been measured to be 0.05×10^{-24} cm² at 84 Mev. This of course means that the efficiency of the counters is low, since the useful thickness of the Bi layers is limited by the range of the fission fragments. In fact, to take survey data in fields of a few high-energy neutrons per cm² per second, it is necessary to use counting periods of the order of hours. However, the method has frequently proved useful, since little else is available as a survey meter. A rough absolute efficiency is calculable from the above cross section, the ranges of fission fragments, and from geometrical considerations on the emergence of the fragments from the Bi layer.

* * *

It is a pleasure to acknowledge the association with Messrs. W. E. Nolan, W. Patterson, B. W. Thompson, A. Redmond, and Dr. R. L. Mather, in the application of several of these techniques and in the development of a few of them.

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OIL-COOLED CYCLOTRON destroyed by fire. When restored, the cyclotron was redesigned with water as the cooling medium

Cyclotron Safeguards

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IN PLANNING the construction of a cyclotron, one must consider: (1) the safety hazards to personnel operating the cyclotron and performing necessary repair or alteration work, (2) safety hazards to others in the neighborhood not concerned with the operation of the cyclotron, (3) fire hazards inherent in the apparatus itself, and (4) possible loss or damage to the cyclotron from an exposure fire—that is, a fire involving the building housing the cyclotron or other nearby structures.

Because the director of any such project usually faces serious budgetary problems, he is reluctant to divert any funds from the cyclotron to even such a necessary evil as the roof over his head. All such "subsidiary items" he is inclined to evaluate on the basis of cost alone. Whether in industry or in research, the fallacy of this reasoning must be recognized.

Emphasis on the excellence and design of the equipment itself for the scientific purpose intended has often led to incorrect evaluation of other important factors. Lack of exact knowledge of the physiological effects of chronic exposures to certain types of radiation has sometimes caused the use of excessively high safety factors. Lack of appreciation of other factors has sometimes created serious operational problems. But, more specifically, the planning that has gone into the elimination of radiation hazards has often almost entirely overlooked the ordinary hazards of fire and accident.

While this paper is directed mainly to cyclotron projects, the principles discussed are equally applicable to the construction and operation of such particle accelerators as Cockroft-Walton multipliers, Van de Graaff generators, linear accelerators, synchrocyclotrons and betatrons.

Fire and Accident Considerations . . .

There are no mysterious fire or accident hazards with particle accelerators as such that the application of sound protection principles developed over the years cannot guard against. The nature of many of these hazards has long been known, but recent accidents point to a need for re-examination of safeguards for them.

Cooling Media

The fundamental decision on how a cyclotron will be cooled has an important bearing on fire-protection considerations. Both water and oil have been used as the cooling medium, and there are undoubtedly advantages in each method. It is significant, however, that an oil-cooled cyclotron recently destroyed by fire (see photograph above) has been restored as a water-cooled cyclotron.

Regardless of the fact that a high flash oil may be used or that the system may be completely enclosed, there can be no guarantee that an arc cannot be struck to the oil containers. If, in addition, cyclotron shielding is such

Actual operating experience is showing up many fire, accident, and radiation hazards in accelerator designs. This article describes specific dangers and advises how to avoid them

130-INCH CYCLOTRON at the University of Rochester is protected from a transformer fire by the blocking up of a window as shown

that the apparatus is actually built in a vault, then the fire fighting becomes a difficult operation for even the most modern municipal fire department.

Even if the fire is extinguished in a reasonable time by the best available manual equipment in the hands of competent men, the damage may be well nigh total.

The smoke from an oil fire and from electrical insulation is heavily sulfur bearing. When such smoke is deposited on relay contacts and other delicate electronic equipment, sulfuric acid is formed and contacts freeze. The result is that equipment not directly damaged must be torn down and checked to determine to what extent this particular type of damage has occurred.

The only satisfactory protection for an oil-cooled cyclotron located in a vault is automatic, carbon-dioxide, total-flooding protection. In such a system, an increase in the temperature at a rate exceeding normal causes the automatic discharge of carbon dioxide gas into the entire area. Simultaneously, the area is sealed by automatic closing of doors, shutting down of air-conditioning systems, etc. The system is based on the principle of inerting the atmosphere with the result that fire cannot survive. After a suitable waiting period, the vault can be opened up, the carbon dioxide blown out, and the damage repaired. An alarm bell and delayed operations are provided as safety factors to personnel working in the area, that is, the sounding of the alarm permits evacuation of personnel prior to the release of carbon dioxide.

If a cyclotron shielded by a vault is to be built, the engineering estimate comparing water-cooled and oil-cooled cyclotrons should include an item for the automatic CO_2 system in the cost of the oil-cooled cyclotron. This might well be enough, with other factors, to swing the decision toward the water-cooled cyclotron. From the fire-protection standpoint, this is ideal, since it is obviously more desirable not to have a hazard than to have a hazard existing even with the best possible protection.

The question of cooling medium resolves itself to a choice between oil and water. Air is too noisy and commercial coolants of the diphenyl type generally present a health hazard and can cause corrosion if moisture is present. Those who favor oil argue that oil-cooled apparatus has the benefit of long experience in fabrication and avoids electrolysis, clogging through corrosion, and leaks. On the other hand, one large cyclotron has used distilled water in stainless-steel tubing for five years without any difficulty.

A hazard not always appreciated in accelerator construction is that of oil-cooled transformers. They should be so installed that, in the event of a fire in a transformer, the transformer can burn out without doing any damage to the accelerator or its building.

See the picture above. In this particular instance, such transformers were installed outside the building, but immediately adjacent to an ex-

MOVABLE HAND-TOOL RACK contributes to orderly operation of 130-inch cyclotron at the University of Rochester

tremely large plain glass window. Possibilities of serious fire damage to the accelerator in the event of a fire in the transformer were readily apparent and the situation was corrected by closing up the window with bricks. Transformers cooled by air or a nonflammable coolant are preferable to oil-cooled transformers.

Flammable Liquids

When pumping down, moisture is most safely removed by means of liquid nitrogen or electrical drying units. The use of alcohol or acetone-dry ice mixtures can create extremely dangerous hazards. A familiarity with flammable liquid hazards is a requisite in designing such equipment.

Paraffin Fire Hazard

Radiation protection as such will be discussed in later paragraphs. One type of radiation shielding, however, has a definite bearing on the fire hazard. Water, a magnetite concrete mix, and paraffin are all technically suitable materials for shielding. However, paraffin can be used for shielding apparatus, such as a collimator, with reasonable safety only if the apparatus contains no electrical equipment that might arc and set the paraffin on fire or if there is no other combustible material present in sufficient quantity to vaporize and ignite the paraffin.

The use of paraffin for general shielding such as walls or ceilings has been considered when cyclotrons are to be built in existing buildings. This is extremely dangerous. If a fire sufficient to ignite the paraffin occurs, there will be an extremely hot, smoky and dangerous fire that will certainly destroy the cyclotron and seriously endanger, if not, destroy the building. Water or a magnetite concrete should be used instead. If neither is practical for the ceiling, then the occupancy above should be changed, as it was in one case, from a classroom to a storeroom.

When a building is specially built to house the cyclotron, there is no reason even to consider the use of paraffin for general shielding.

Fire Alarms

Since an accelerator sometimes operates for many hours without shutdown in an area from which personnel are necessarily excluded, the problem of whether the building should be provided with an automatic fire alarm system must be solved. The answer to it depends upon the amount of combustible material involved.

If an oil coolant is used and an automatic CO_2 flooding system has been provided, the system itself will serve as an alarm. If no great amounts of combustible material are present, the accelerator is water-cooled, and it is located in a noncombustible building, a fire-alarm system is probably unnecessary particularly since any malfunction will show up at the gages in the control room. However, if there is any possibility of an undetected electrical fire, then the area should be covered by a smoke-detecting fire-alarm system.

Building

A major item to be considered is the building itself. Preferably, this should be an entirely detached structure constructed for the purpose. When accelerators are installed in existing buildings, they are generally located in basements because of the weight problem and the shielding provided by subgrade construction. This makes the accelerator subject to damage both by water and by smoke from a fire any place in the building.

Consideration should be given to the possibility of fires in other parts of the building and an estimate made of their possible effect on the accelerator project.

Fire doors, fire walls, sump pumps, and other such devices can be used to provide a physical cutoff for the accelerator area from the rest of the building and for the automatic removal of any surplus water.

Connections to the air-conditioning system must be carefully made to guard against the possibility of the accelerator area's becoming charged with smoke from fire elsewhere in the building. All things considered, a separate detached building housing the accelerator is most satisfactory.

The accelerator building should, of course, be at least *noncombustible*, that is, constructed of materials that will not in themselves burn. An example of a fairly inexpensive noncombustible building is one of unprotected steel framing with the walls and roof of corrugated asbestos. If sheet metal is used, the type that is weather-protected with bituminous coating should be avoided since such coatings create a bad fire risk.

If the cyclotron itself contains no fire hazards and its associated equipment does not represent a large volume of combustible material, construction using noncombustible materials is adequate. However, if there is a considerable body of fuel, such as an oil coolant, or a tremendous quantity of combustible interior partitioning that may become ignited, then the building itself must be protected against the fire in the contents. Thus, the building must be *fire resistive;* that is, the structure of the building not only must not contribute to the fire but must resist distortion and destruction by fire. In general, this means either reinforced concrete construction or steel-frame construction with the steel members protected from heat in an approved manner.

Again the soundness of the policy of eliminating hazards rather than

protecting against them appears evident. Noncombustible construction is much less expensive than fire-resistive construction. It compares favorably in initial cost and extremely favorably in maintenance with wood-frame construction.

Control-Room Paneling

Control rooms are often paneled with combustible fiberboard sound-conditioning material. Even the apparently slight amount that is needed to soundproof the control room could feed sufficient fire to do extensive damage to the control room equipment. Sound-conditioning materials, when needed, should be noncombustible, such as those made of glass or steel.

Storage Space, Tidiness

It is good practice in the original design to provide for a storage room for equipment that may be used only occasionally. Such an arrangement discourages the creation of a junk heap that often arises in the corner of a cyclotron room and is, in itself, the worst sort of fire hazard. If possible, the storage room should be located in a detached building.

One project provided such a storage room in a detached building but then used it to house the motor generator for the cloud chamber. It was necessary, then, to install a fire wall to protect the generator from a possible fire in the rest of the building.

Tidiness in the vicinity of a cyclotron contributes to the lessening of accident possibilities. A tool rack, such as the one seen in the photograph on the left, helps to keep tools accessible and out from under foot. Built-in shielding, as provided around the Brookhaven cyclotron (see photograph on the next page), often results in more work area and consequently, more safety for personnel.

Personnel Safeguards

Another important point is to provide as nearly a foolproof method as possible of assuring that no person can be left in the cyclotron area and that no person can blunder into the area when the cyclotron is in operation.

In one case, safeguards for a pipe tunnel which leads directly into the cyclotron area were not provided and any unsuspecting plumber tracing a line could have entered the cyclotron while it was in operation without the knowledge of the operating personnel.

In another case, an elaborate interlock system was founded on the fact that only one key was made for each of several locks to doors to buildings within the cyclotron area. It was necessary that all of these keys be placed in respective locks in an interlocking device before the cyclotron could be operated. This did not prevent a construction contractor's employee being left in the cyclotron area when a magnet was turned on. He was working below the cyclotron and departed in haste when a steel wrecking bar pulled itself out of his hands and attached itself to the ceiling!

Miscellaneous Precautions

In connection with the operation of a cyclotron, many projects have machine shops and chemistry laboratories but their hazards are well known and need not be enumerated here. The chief hazards found around accelerators come from improper electrical wiring with its resultant electrocution possibilities and poor housekeeping which leads to falls and other similar injuries.

Emergency lighting facilities, which may range from flashlights attached to the wall to automatic systems should be provided for any accelerator housed in a building without natural light.

A formal procedure should be provided for re-energizing the electrical system in the event of a power failure which may involve circuit breakers, transformers, substations, etc. For example, in the absence of such a procedure, the premature or haphazard closing of a circuit breaker could result in the electrocution of a person searching for the cause of the trouble at another location in the line.

All electrical equipment should be designed and installed in accordance with the National Electrical Code. In addition, realistic provisions should be made for future changes and temporary setups so that adequate facilities will be provided for electrical service to such apparatus. This will eliminate such hazards as temporary connections to open switch boxes and floors littered with extension cords of all descriptions.

It is usually best to purchase standard units wherever possible or have them built by a reputable manufacturer under contract. Homemade equipment often lacks such safety devices as interlocks and thus creates extremely dangerous conditions.

Compressed-gas piping installations, such as for hydrogen, are also the subject of standard codes which should be observed since they represent the synthesis of many years of experience, some of which, unfortunately, has been bitter.

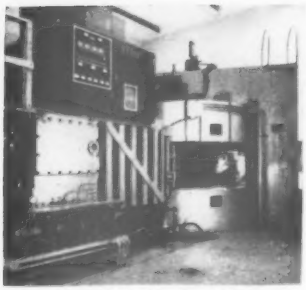
Representatives of the local fire departments should become familiar with the project lay-out and its operation. This can often be accomplished by brief guided tours. The negligible radiation hazard which exists when the cyclotron is shut down should be carefully explained so that the fire fighters will feel free to carry on work in the event of an emergency once they are assured the power is cut off.

Radiation Protection . . .

Before approaching any radiation shielding problem, one must understand the distinction between radiation levels required from health considerations and levels dictated by the necessity for keeping a low background. These two criteria can differ by two or three orders of magnitude with corresponding differences in shielding cost.

Areas where low-level radiation measurements are to be carried out should be kept as remote from sources of radiation as possible. It is usually not economically feasible to design all areas so that the radiation levels are down to the order of background merely on the chance that low-level work might occasionally be done more conveniently in these areas. This type of reasoning has been prevalent in the past with the resultant expenditure of funds that could be used more effectively for other needed safety measures.

The shielding required for any accelerator depends on such factors as the type of particles accelerated, their terminal energy, the duty cycle of the unit, and the distance from the nearest occupied areas. An exhaustive study is required in the design stage of the shielding needed for both the primary particles (those in the beam and any that may be scattered from targets or other parts of the equipment) and any secondary radiation such as brems-



60-INCH CYCLOTRON at Brookhaven National Laboratory. Note tidiness and the fact that built-in-wall shielding permits ample work space

strahlung (X-rays) that may be produced by the stopping of high-velocity particles or radiations. The latter consideration, which results from nuclear transformations in the target material, can be deceiving. It would first appear that from an accelerator of a given maximum energy, say 0.5 Mev, the maximum energy of any radiation emitted will be 0.5 Mev. Actually, if such an accelerator, for example, were to be used for bombarding a lithium target with 0.5-Mev protons, gamma radiation of energies thirty five times as high (17.6 Mev) could result. Similarly there are many neutron reactions that result in energetic gamma radiations being emitted.

Another source of radiation that might be unexpected is that caused by reverse currents. In proton accelerators of certain types, there is a considerable flow of electrons from the normal target to the proton-source end of the evacuated chamber. These produce X-rays, which become an important design consideration.

Investigators who have had shielding experience with other types of radiation must discard many of their conceptions when dealing with neutrons.

In planning shielding for neutrons, they must consider them almost as a gas. In addition to having the proper thickness of shielding material, it should be continuous around the source much as a gas container must be continuous to avoid leaks. Neutrons emitted from even a small fault will diffuse through the air and surround the entire shield.

In general, the maximum permissible levels of radiation have been established for long-term continuous occupational exposure. In many accelerators, the particle beam is pulsed, having very low duty cycles. This results in extremely short intervals of high radiation rates. It is generally agreed that, for occupational tolerance levels, the time-dose-rate relationship is unimportant as long as the total weekly exposure to an individual is below a given limit. Some authorities believe this integration period should be extended to several months. Although the hazard (or lack of hazard) has not been definitely established, there is no reason to believe that a worker cannot be safely exposed to his weekly dose limit in a fraction of a microsecond as long as he is exposed to no more radiation for the period. This might pose an administrative problem, but the practice would save considerable shielding for special problems.

Target Handling

A radiation-exposure problem associated with accelerator programs is that of target handling. Target materials under the influence of particle bombardment frequently become highly radioactive. Serious consideration should be given to the planning of remotely controlled target removal, as well as to the planning of transportation and storage of targets.

The target material often has to be set up quickly for the study of short-lived radiations. In the interests of expediency, the adequate protection of handlers is likely to be disregarded. At Berkeley, this problem has been solved by a pneumatic-tube system for the transmission of targets to the radiochemistry laboratory.

Other parts of the equipment subject to bombardment may also become radiation hazards through induced radioactivity, and any servicing should proceed with appropriate caution.

Shielding

One of the most frequently encountered sources of shielding difficulties is a departure from original plans. It is hard, in this fast-changing field, to predict all the possible uses of an accelerator. The design should, therefore, provide space for the addition of extra shielding should the need arise.

Such fundamental design considerations as location of building, above versus below ground-level construction, remote versus nearby heavily shielded controls or a combination of both, etc., involve so many questions of operating practice that actual operating experience as an adjunct to pure theoretical reasoning is the best reference an accelerator designer can have.

Shielding designers frequently make the mistake of basing their design on published absorption coefficients. Such coefficients are often either the result of measurements made with a narrow collimated beam of radiation or the result of calculations based on considerations of radiation energy and the atomic number and density of the absorber. These values, particularly for electromagnetic radiations, usually differ sharply from actual measurements made with a source radiating in all directions and surrounded by the shielding materials encountered in practice. The principal reason for this is in differences in scattered radiation received from the absorber itself under different geometrical arrangements.

Another pitfall of designers is in attempting to use reliable shielding data for certain energies and extrapolating to higher energies for which no data exist. For some of the newer high-energy equipment, there has been no alternative, but these cases serve to emphasize the advantage of allowing for the addition of extra shielding should it be required.

Even with radiations other than neutrons, the diffuse scattering from air becomes considerable under certain conditions. Roofs of accelerator enclosures may require additional shielding after operation has started because of excessive skyshine radiation (scattered back by air) to areas adequately shielded from direct radiation. In one instance, the existence of soft air-scattered gamma radiation outside of a building prevented the opening of windows in a control area in the summertime.

Obviously, there are many safeguards to be included in the design of an accelerator in addition to the points discussed in the previous paragraphs. However, it is hoped that this review will at least indicate the major features to be included and errors to be avoided.

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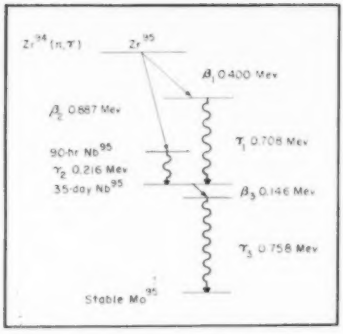

FIG. 1. Decay scheme of Zr^{95} and Nb^{95}

Radioactivation Determination of Zirconium in Zr-Hf Mixtures

Zr concentration, in mixtures ranging from nearly pure Zr to as little as a few tenths ppm, can be determined within about 1% by combining slow-neutron activation and radiochemical separation as described

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THE NEUTRON INTENSITIES available in a chain-reacting uranium pile enable analyses to be performed for minute concentrations of most of the stable elements (*1*). The radioelements that are usually formed in the greatest abundance are those produced by the simple capture of a neutron. Upon capture, gamma rays are emitted. These reactions are the so-called (n,γ) reactions, and the primary radioelement formed has the same atomic number as that of the stable element which captured the neutron.

Several radioactivation methods have been based on the isolation of the stable element along with the nuclide isotopic with it and the measurement of the radioactivity as a means of determining the concentration of the stable element in the sample (*2–6*). Under certain conditions, a chemical separation is not necessary and the radioactivity of the desired isotope can be determined by energy and/or decay measurements. The limits of detection for the method are usually in the range of a few parts per million or less (*1*).

Determining the zirconium concentration in samples of hafnium is complicated by the similarity of the chemistry of these two elements. A simple way to circumvent the separation problem is to take advantage of the decay scheme of Zr^{95} (*17–22*).

From Fig. 1, it can be seen that, since the amount of Nb^{95} radioactivity formed by bombarding Zr^{94} with neutrons can be determined, and since the concentration of Zr^{94} in the sample can be calculated from the amount of Nb^{95} radioactivity found, an analysis for zirconium can be performed without separating it from hafnium.

The procedure follows for calculating the Nb^{95} activity present at the end of the neutron irradiation.

Formation of Zr^{95} by a neutron irradiation is accompanied by the growth of Nb^{95} from the Zr^{95} previously formed. If the intensity f (in n/cm²/sec) of the neutron flux of the reactor is assumed constant, the formation of Zr^{95} by an irradiation of t_1 seconds is given by the equation

$$A_1 = (N)(f)(\sigma)(1 - e^{-\lambda_1 t_1}) \quad (1)$$

where A_1 is the Zr^{95} activity in disintegrations per second, N is the number of Zr^{94} atoms exposed to the neutron irradiation, σ is the neutron cross section of Zr^{94} in cm², and λ_1 is the decay constant of Zr^{95} (*7*).

The growth of Nb^{95} during the irradiation is given by the equation

$$A_2 = \frac{(B)(f)(N)(\sigma)}{\lambda_2 - \lambda_1} \times [\lambda_2 - \lambda_1 - \lambda_2 e^{-\lambda_1 t_1} + \lambda_1 e^{-\lambda_2 t_1}] \quad (2)$$

where A_2 is the 35-day Nb^{95} disintegration rate after an irradiation of time t_1, λ_2 is the decay constant of 35-day Nb^{95}, and B is the fraction of the Zr^{95} disintegrations which results in the direct formation of the 35-day Nb^{95}

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Preparation of Sample Prior to Counting

The capsules containing radioactive hafnium and zirconium oxides (known amounts of zirconium oxide had been added to 100 mg of hafnium oxide before the irradiation) were broken under concentrated sulfuric acid and the mixture heated until complete solution of the oxides was obtained.

The solution was cooled, diluted to a known volume (50 ml) and an aliquot (2 ml) removed to a 50-ml glass centrifuge tube. Then 8 ml of distilled water, 10 ml of concentrated nitric acid, 1 ml of 6*M* hydrochloric acid, 1 ml of saturated oxalic acid, and 2 ml of standardized niobium carrier (20 mg Nb) were added. The solution was heated nearly to boiling and 0.5 gm of potassium chlorate added in small portions. The solution was boiled for a few seconds after each addition.

The niobium oxide was separated from the solution by centrifuging and the supernate removed by decantation. To the precipitate, 3 ml of 6*M* nitric acid, 2 ml of 6*M* ammonium hydroxide, and 5 ml of distilled water were added. The mixture was stirred, heated, and transferred to a 50-ml Lusteroid tube. The supernate was removed by decantation after centrifuging and the precipitate dissolved in 1 ml of 48% hydrofluoric acid; 2 ml of 6*M* nitric acid, 1 ml of a solution containing 10 mg/ml of zirconium as the nitrate, and 5 ml of distilled water were added. After stirring, 1 ml of a solution containing 50 mg of barium as barium nitrate was added dropwise.

The mixture was stirred, centrifuged, and the supernate transferred to a second Lusteroid tube. A second aliquot (1 ml) of zirconyl nitrate solution was added and the barium fluozirconate removed as before. Concentrated ammonium hydroxide was added to the clear supernate from the barium fluozirconate precipitation until a red phenolphthalein color was observed. The niobium oxide precipitate was removed by centrifuging.

The precipitate was washed twice with a mixture containing 1 ml of 6*M* nitric acid, 3 ml of 6*M* ammonium hydroxide, and 5 ml of water. The second wash solution was used to transfer the precipitate to a 50-ml glass centrifuge tube. After heating and decantation of the second wash solution, the precipitate was dissolved by adding 0.5 ml of 6*M* nitric acid and 2 ml of saturated oxalic acid and heating. Then 3 ml of distilled water and 5 ml of concentrated nitric acid were added, the solution heated nearly to boiling, and 0.5 gm of potassium chlorate added in small portions. The mixture was boiled after each addition. The niobium oxide was separated from the solution by centrifuging and decanting the supernate.

The precipitate was washed with a hot solution containing 3 ml of 6*M* nitric acid, 2 ml of 6*M* ammonium hydroxide, and 5 ml of distilled water. The precipitate was separated from the wash solution by filtration. The filter paper and precipitate were transferred to a crucible, the filter paper ashed and the precipitate ignited at 800° C for 15 minutes.

The ignited precipitate was transferred to a tared watch glass (1 inch in diameter) and the chemical yield through the procedure was determined by weighing.

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isomer. The value of B has been given as 0.98 (*8*).

A similar equation is applicable to the determination of the 90-hour Nb^{95} disintegration rate after an irradiation time t_1. In this equation, λ_3, the decay constant of the 90-hour Nb^{95} isomer, is substituted for λ_2, and the value of B is 0.02 (*8*).

The neutron flux of the pile (*9*) used was approximately 10^{12} n/cm²/sec, and, since the cross section of Zr^{94} has been given as 0.08 barns (8×10^{-26} cm²) (*10*), the substitution of these values in Eq. 2 indicates that by irradiating 2 micrograms of zirconium of natural isotopic composition for a time sufficiently long to make the value of the $e^{-\lambda_1 t_1}$ factor small in comparison to unity, a Nb^{95} counting rate of approximately 10 times background would be observed. Such counting rates can be easily determined.

The 35-day Nb^{95} activity A_{31} present at a time t_2 after removal of the sample from the pile is given (*11*) in the usual exponential equation

$$A_{31} = \frac{A_1\lambda_2}{\lambda_2 - \lambda_1} \times (e^{-\lambda_1 t_1} - e^{-\lambda_1 t_2}) + A_2 e^{-\lambda_2 t_2} \quad (3)$$

where A_2 is the disintegration rate of the 35-day isomer from Eq. 2.

An equation analogous to Eq. 3 is applicable to determination of the disintegration rate A_{32} of the 90-hour Nb^{95} isomer at time t_2, and λ_3, the decay constant of the 90-hour isomer, is substituted for λ_2 in Eq. 3. Since the decay of the 90-hour isomer results in the formation of an additional amount A_4 of the 35-day isomer, for exact determinations, this quantity must be added to the sum of A_{31} and A_{32}. However, since A_4 represents a small contribution to the total 35-day Nb^{95} activity in comparison to that formed directly from Zr^{95} and to the counting errors involved, it is neglected in later calculations.

The neutron flux to which the sample was exposed may be determined by exposing a monitor of known neutron cross section at the same time and position in the pile. Neutron intensity can then be calculated from the radioactivity of the monitor and the decay scheme of the radioisotope produced.

A simpler and more accurate method involves the irradiation of a known amount of zirconium at the same time as the unknown samples are irradiated, but the Nb^{95} activity isolated from the zirconium monitor and the unknown sample is corrected beforehand to an arbitrarily chosen time base. This is done by using a simple proportion for calculating the zirconium concentration of the unknown, as described later.

Since the cross section of hafnium for pile neutrons is high, the neutron intensity toward the center of a thick target of hafnium will be less than that at the outside of the sample. The neutron intensity f at a distance ΔX from the outside of the target (*7*) is

$$f = f_0 e^{-\sigma N_v \Delta X} \quad (4)$$

where f_0 is the neutron intensity at the outside of the target, σ is the cross section of hafnium in cm² atom and

N_x is the density of the sample in atoms/cm³.

The average neutron intensity to which the sample was exposed can be obtained by integrating Eq. 4 between the limits 0 and ΔX. The importance of this correction is negligible for the experiments cited below, since the distance ΔX was less than 0.5 mm for all samples, and the neutron attenuation was approximately the same for each of the samples.

The samples were sealed in small quartz capsules for the irradiation. Aluminum capsules could have been used since the cross section of both materials is low (*10, 12*).

Several types of chemical separation schemes may be used for the isolation of the niobium from the other activities formed by neutron capture. The method developed by Glendenin (*13*) proved applicable with slight modification to the Hf-Zr system.

The steps in the preparation of the sample prior to counting are outlined on the opposite page. For counting, the watch glass containing the niobium oxide precipitate was mounted in the center of an aluminum tray and covered with a thin sheet of aluminum (~2.5 mg/cm²).

The radioactivity of the sample was determined by using a flow-type counter attached to a commercial scaler (Nuclear Instrument and Chemical Corp. Model 163). The flow-type counter was constructed at the New Brunswick Laboratory. A helium (98.7%)-isobutane (1.3%) mixture was used as the counting atmosphere.

Discussion and Results

The synthetic samples used to test the procedure were prepared by adding known amounts of zirconium as zirconium oxide to a hafnium oxide sample containing approximately 1% zirconium. A sample of hafnium containing less zirconium would have been preferable; however, the separation of these two elements is difficult, and such a sample was not available to us.

The observed activities were corrected for chemical yield (usually 50 to 90%) and for the growth and decay of Nb^{95} which occurred after removal from the pile. Since the observed Nb^{95} activity will consist of contributions from both the 35-day and the 90-hour isomers, the ratio of the number of Zr^{95} disintegrations, which result in the direct formation of the 90-hour Nb^{95} isomer, must be utilized in making the corrections.

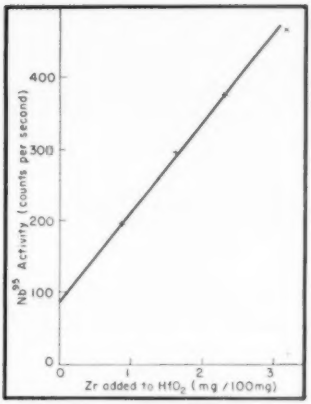

FIG. 2. Niobium activity as function of the inactive zirconium added to hafnium oxide

Two minor complications arise in correcting the counting rate data to a definite time base; these are:

1. A factor must be determined with which to convert the counting rate to a disintegration rate, or the counting rates must be related to the disintegration rate by a constant. Also, the neutron flux, f, must be known accurately or a comparative method must be used which will negate the inaccuracies caused by assuming a value for the flux. Since the counting-rate determination was made in such a manner that the factor for converting the counting rates to disintegration rates was a constant, the counting rate was used directly in determining the Zr concentration of the hafnium.

2. Since the ratio of the Nb^{95} radioactivity at the time of chemical separation (t_2) to that at the time of removal of the samples from the pile (t_1 in Eq. 2) will be a constant for a given set of values of t_1 and t_2 and the value of this ratio will be independent of the value of the neutron flux, it was used to correct the observed counting rates to the counting rates observed at t_1.

In Fig. 2, the corrected counting rates are plotted against the milligrams of zirconium added to the hafnium oxide. Since the points fall almost exactly on the straight line, it is evident that the determination of the slope and of the zero-added zirconium intercept can be accomplished accurately. The sample of hafnium oxide contained 0.71% zirconium.

The samples to which this method is applicable may be of almost any composition. It was applied to the nearly pure hafnium system to demonstrate the absence of interference by hafnium. The usual analytical methods for determining zirconium cannot differentiate between hafnium and zirconium. Therefore, the analyses so obtained will be subject to errors equivalent to the hafnium contamination of zirconium in nature.

The presence of nonradioactive niobium does not interfere with the zirconium determination. The activities produced by Nb^{93} neutron absorption have half-lives of 6.6 min (*14*) and greater than 100 years (*15*), and within a short time after the irradiation no interference is observed. Interference by uranium can be eliminated by separating Ba^{140} from a part of the sample and calculating the amount of fission niobium present by using a fission yield curve (*16*).

* * *

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1.2-Mev Accelerator at the Australian National University

First operated last January, this machine was pictured on the cover of the April NUCLEONICS. It is described more completely in this article

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IN THE NEAR FUTURE, two accelerators will be operating at this laboratory. The one described here is an air-insulated machine made up of the three main parts shown in Fig. 1. The other, a 2-Bev proton cyclo-synchrotron, is under construction.

High-Voltage Generator

This seven-stage voltage-multiplying circuit was developed by the Philips Co., Eindhoven, The Netherlands, from the original circuit of Cockcroft and Walton (*1*). Each stage is rated at 200 kv, and an open-circuit voltage of 1.4 Mv is expected. At the rated load of 3 ma, with the first stage near its rated voltage, a terminal voltage of 1.2 Mv is obtained.

A simplified version of the generator circuit is shown in Fig. 2. The capacitor in each stage is 0.02 μf. Nine-section mercury rectifiers, Philips type 28216, make the compact design possible and eliminate difficulties from rectifier voltage drop at high currents.

The problem of heating the cathodes has been solved by the use of a radio-frequency system described by Douma and Brekoo (*2*). In this system, the capacitors in the multiplying circuit form a loop that, with capacitors C_R and C_R' and chokes L, L_1 and L_2, enable high-frequency power to be fed to the top of the generator and down again. The inductance L prevents r-f current from entering the secondary of the high-voltage transformer. The series reactance L_1C_R' by-passes the uppermost rectifier. Direct current is delivered to the top terminal through the high-frequency choke L_2.

Between each pair of capacitors in the loop, a small autotransformer supplies the appropriate rectifier filament. The circulating r-f current is about 250 ma at 250 kc, and the current supplied to the filament is 3.5 amp at 2.3 volts. Adjustment to obtain correct cathode heating is achieved by frequency and power variation of the oscillator, plus use of taps on the individual filament transformers.

If the rectifiers are assumed to be perfect, an analysis of the circuit indicates that the peak-to-peak ripple in the output at the maximum load of 3 ma is 21 kv. This is much too large for many experiments, and a smoothing circuit is needed.

Smoothing Circuit

Besides reducing ripple, the smoothing column of capacitors is used to supply appropriate d-c voltages to the lenses of the seven-stage accelerator tube, as shown in Fig. 1. If the cross-connecting resistances R_2 were not present, the smoothing ratio obtained from the circuit made up of R_1 and the seven 200-kv 0.02 μf capacitors in series would be 1:27 at the fundamental frequency of 200 cps. Under worst conditions this would mean a 770-volt ripple, peak to peak. But the insertion of R_2 reduces the efficiency of the filter by some 40%, and, also, the shunt path across R_1 created by the capacity between the generator and the smoothing-column electrodes, as well as the capacitative feed-through from the a-c generator column and the smoothing column, has a deleterious effect on the smoothing.

On the positive side, the surge-limiting resistor R_s forms a further filter with the capacity to ground of the accelerator-tube top electrode, giving a smoothing ratio of 1:2. With the layout as adopted, the net result is an estimated ripple at the accelerator tube of 90 $\pm$ 10 volts per ma load, plus 70 $\pm$ 15 volts per 100 kv over-all. At 1 Mev with a beam current of 250 μa, the total current drawn from the generator is just below 2 ma, giving a ripple voltage of about 1 kv.

No measurements have been made of the effect of the spark gaps S on smoothing.

The ripple at the top of the filter stack is almost sinusoidal at 200 cps.

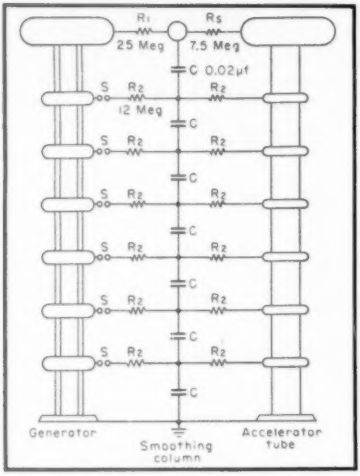

FIG. 1. Schematic circuit of smoothing filter, generator and accelerator tube

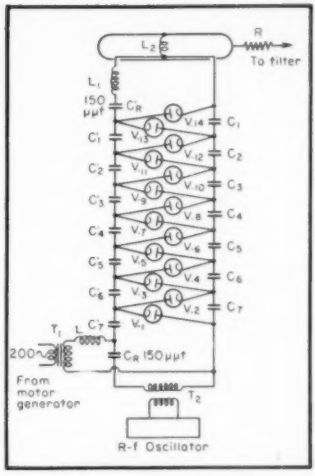

FIG. 2. Circuit diagram of multiplying circuit of generator

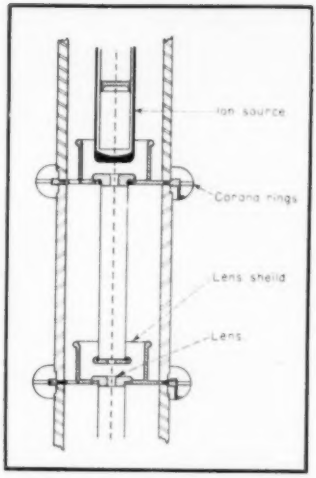

FIG. 3. Section of vertical accelerating tube showing construction

By insulating the base of the smoothing column from ground, an a-c voltage of correct frequency, phase and amplitude can be injected; this should completely cancel the fundamental. The remaining ripple at the accelerator tube will then be mostly the first harmonic; its estimated amplitude is less than 100 volts.

Current flow through R_1 and R_s leads to a voltage drop of 15 kv/ma. At full output, therefore, the maximum accelerating voltage will be just below 1.2 Mv.

Accelerating Tube

A section of the seven-stage accelerating tube, essentially the design of Bouwers except for the vacuum seals, is shown in Fig. 3. The system has two advantages. First, it gives a low X-ray background since the small lens aperatures effectively prevent secondary electrons travelling up the tube from acquiring more energy than is imparted by one stage. Second, the cylindrical lens shield prevents it from viewing the walls of the tube.

The entry and exit lens apertures are 2.5 and 2.0 cm in diameter respectively. The lens faces and the toroid crowning the shield are of highly polished stainless steel; the rest of the electrode structure is mild steel. Mechanical line-up of the system is effected by grinding the porcelains at each end to fit snugly into accurately turned shoulders in the mounting rings. When the tube is evacuated, the porcelains locate on the rings, giving rigidity and preventing the rubber gaskets from being exposed inside the tube.

The pumping system is conventional, with a mechanical pump backing up an 8-in. diffusion pump. A pressure of 2×10^{-6} mm Hg is achieved with the ion-source gas turned off.

An Oliphant-type (*3*) ion source is now used. This has a large gas consumption; giving a pressure in the tube of $5\text{–}8 \times 10^{-5}$ mm Hg under optimum beam conditions. The low proton percentage ($\sim$30) and high energy spread of the ions (up to 30 kv) also make this source unsuitable. An r-f ion source is now being constructed (*4*) that will use less gas, give a proton percentage of 80 or 90, and have an energy spread that will be small as compared to the ripple voltage.

With the present source, the focus 5 ft from the bottom lens is such that a spot 5 mm in diameter containing 200 μa of beam can be held from 450 kv to maximum. The largest beam to date was 300 μa at 880 kv.

An oil-cooled measuring resistance is incorporated in one of the insulating supports. It is constructed of 1,500 1-megohm resistors in series, placed helically on a plastic former. This will be calibrated at 440 kev and 873 kev against the (p,γ) resonances of Li and F. The remaining supports carry oil cooling for the ion source, a belt drive for the ion-source motor-generator set, and the Selsyn-driven rods for controlling the ion source.

Target Room

The accelerator tube stands on the roof of the 40 × 25-ft target room. This room has a 9-ft ceiling, and part of the roof and walls can be removed to reduce scattering.

The beam enters the target room vertically and is turned 90 degrees by a magnet having a 40-cm radius of curvature. Wedges that fit into the pole faces at beam entry and exit provide field shaping, making double focussing of the beam possible (*5*).

* * *

his equipment was brought into operation by a team including F. C. Horsman of Philips, Eindhoven, F. Dickson of Philips Australia Ltd., and E. K. Inall and N. F. Bowkett of the university staff.

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STORAGE shelves for materials to be dated by Libby's process at Yale Geochronometric Laboratory. E. S. Deevey is holding container of shells from Japan

G-M COUNTER for measuring C-14 activity being inserted into ring of cosmic-ray counters

Determination of Geologic Time

Most of our knowledge of the absolute chronology of the sequence of the earth's strata rests on radioactivity methods. This paper is a basic review of these methods for calculating geologic ages

By RICHARD L. BURLING
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NATURAL RADIOACTIVITY has become the sole method of dating events through most of geologic history. Studies of tree rings, of pollen counts, and of varved clays permit the dating of very recent events only.

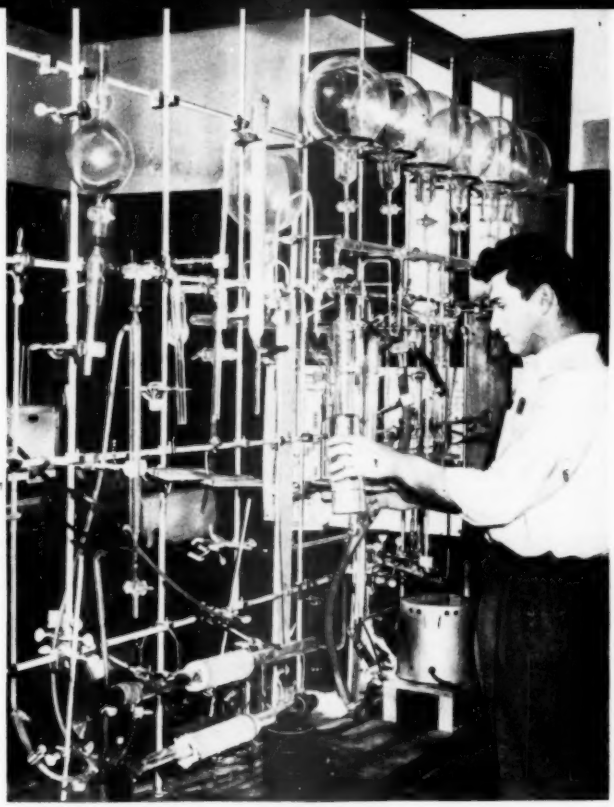
The ages that can be determined by the techniques discussed here are the intervals between the present and events of a particular kind. These events resulted either in the separation of a system from an element factory, or in separation of a larger system into two or more subsystems or phases by a process of a particular kind. Such a process separates elements but does not separate isotopes much; it is capable of altering appreciably the relative concentrations of the parent and daughter elements in the two phases.

Element-separating processes occur only when phase separations occur; i.e. principally in liquids (*1*). Examples are the separation of the earth's mantle from its core, of the metallic and silicate phases of a meteorite, of a phenocryst from its magma, and of an ore mineral from the hydro-thermal solution which deposited it.

Separations such as that of the planets from their parent star, or of a pebble from its parent rock, being unlikely to separate elements, would not be amenable to our methods. An age determination based on radioactivity would "see right through" such an event to the preceding element-separating event.

Single Phase

Let us consider first a single isolated system in which a nuclide A decays by alternative processes, forming B as



CARBON dioxide for the radiocarbon dating process is prepared in this apparatus. The sample of material to be dated is first placed in a heating tube at lower left, and there converted into carbon dioxide. The gas is then purified, and stored in the glass bottles at upper right. For counting the low-level activity of the radiocarbon, the G-M tube containing the sample is placed in a ring of anticoincidence cosmic-ray counters; the counter assembly is shielded from stray radiation by steel plates

one of its daughters. Denote the total disintegration constant by λ, the disintegration constant for the formation of B by λ_B, the atomic abundances of A and B (number of atoms per unit mass of mixed total) by A and B respectively, and the time by t. Then

$$dA = -A\lambda\,dt \qquad (1)$$

and

$$dB = A\lambda_B\,dt \qquad (2)$$

Let i and p refer to initial and present moments, separated by an interval t; $A(i)$ is the initial atomic abundance of A. By integrating Eqs. 1 and 2, we get

$$A(i) = A(p)e^{\lambda t} \qquad (3)$$

and

$$B(p) - B(i) = A(p)\frac{\lambda_B}{\lambda}(e^{\lambda t} - 1) \qquad (4)$$

The left side of Eq. 4 is usually referred to as the "radiogenic" B, the B produced by the decay of A during the time t, with nothing said or implied concerning what happened before the arbitrary instant i.

If only a single mode of decay exists, or if we are concerned with the mode that has by far the largest decay constant, then $\lambda_B \simeq \lambda$, and λ_B/λ can be omitted from Eq. 4. If, in addition, the age is small in comparison with the half-life, then $\lambda t \ll 1$, and $e^{\lambda t} \simeq 1 + \lambda t$, so that Eq. 4 becomes

$$B(p) - B(i) = A(p)\lambda t \qquad (5)$$

If B is formed by decay of more than one parent, say by $A^{(1)} \rightarrow B$ and $A^{(2)} \rightarrow B$, of constants λ_1 and λ_2 respectively, then the Eq. 4 must be generalized to

$$B(p) - B(i) = A^{(1)}(p)(e^{\lambda_1 t} - 1) + A^{(2)}(p)(e^{\lambda_2 t} - 1) \qquad (6)$$

If t is small compared to both half-lives, then

$$B(p) - B(i) = [A^{(1)}(p)\lambda_1 + A^{(2)}(p)\lambda_2]t \qquad (7)$$

Since $A(p)$ and $B(p)$ can be measured, and the decay constants are known, one can solve Eq. 3 for t, if $A(i)$ is known; or one can solve Eq. 4, 5, 6, or 7 for t if something is known about $B(i)$. We will consider four cases: $B(i)$ unknown, $B(i) = 0$, $A(i)$ known, and $B(i)$ known and not zero.

$B(i)$ unknown. Since the initial abundance cannot have been negative, it is possible to find an upper limit to the elapsed time since the system was isolated. Put $B(i) = 0$ and solve Eq. 4, 5, 6, or 7 for t. The numerical solution in this case is the same as that in the next case, and no sharp distinction can be drawn between the two. Even if $B(i)$ is known to have been other than zero, the "uncorrected ages" discussed under the next case give meaningful upper limits.

If the earth's outer crust is the system, we can use the average composition of igneous rocks (*2*) to find an upper limit to its age (*3*). Applying the method to all known naturally radioactive nuclides, the smallest result is about 5×10^9 years, a figure obtained for both U^{235} and U^{238} (*4–6*),

but the results are erroneously referred to as "age of the sun" and "age of the elements" instead of "upper limit to the possible age of the earth's present crust."

If the system is planetary matter in general, we could determine an upper limit to the "age of the elements" if planet formation is not an element-separating process. The necessary data on element abundances might be obtained from meteorites in the way indicated by Brown (7), if his assumptions relative to the origin of meteorites are correct. The calculation has been made by Suess (8) and by Voitkevich (9), but the available data on element abundances in meteorites were so poor as to justify little faith in the results (3).

$B(i) = 0$. This case includes the usual "uncorrected" methods of age determination, which are satisfactory if the initial concentration of the daughter element can be regarded as negligible. Uncorrected ages are very widely used since their calculation requires no isotopic analyses.

Introducing, in Eq. 7, the data for the heavy natural radioelements, using the known abundance ratio $U^{235}/U^{238} = 0.007$, and changing from atomic abundance to mass concentration, or percentage by weight, we have

$$t = \frac{Pb}{U + 0.32Th} 7.25 \times 10^9 \text{ years} \quad (8)$$

or

$$t = \frac{He}{U + 0.24Th} 4.7 \times 10^{10} \text{ years} \quad (9)$$

where *U*, *Th*, *Pb*, and *He* stand for mass concentrations. These are the usual equations for Pb and He ages given by Keevil (10). Similar equations (11, 12) with slightly different numerical constants based on older data are still often used. For older specimens, Pb and He ages must be determined from the more exact Eq. 6. Wickman's graphs (13, 14) are widely used for this calculation.

The Pb method is usually applied to U and Th minerals since they contain sufficient Pb and radioactive parent to be readily determined. Since a chemically separable amount of Pb corresponds to a He content of a few cubic centimeters per gram, the He method is more sensitive than the Pb method, and is applicable to ordinary rocks (15). The usual assumption that no He was initially present is open to some question since there is He in beryl and in some rocks not containing U or Th. This could be primary dissolved He or could originate from decay of a short-lived parent (Ra or Io) or from cosmic-ray reactions (16, 17).

Another difficulty, present also for the other methods, is that the product may be lost by diffusion. Helium is more readily lost than most elements, but seems to be fairly well retained by magnetite (18). Paneth has determined the He ages of iron meteorites (19), but such measurements are questioned by Bauer (20), who regards the He as largely the result of cosmic-ray reactions.

The decay of Rb^{87} has been used by Ahrens (21) to determine uncorrected ages of lepidolites, but his more recent work (22, 23) is on corrected ages.

Khlopin and Gerling (24) have used the formation of several isotopes of Xe from the spontaneous fission of both isotopes of U to determine the age of U minerals from Eq. 4.

The decay of K^{40} to A^{40} has been used by Gerling and Pavlova (25) to derive an age of 3×10^9 years for two meteorites. Suess (26) had used the same decay process to show that the age of certain tektites must be smaller than 10^8 years, which is less than the age of the solar system. His result is an upper limit because the argon content of the gas bubbles in the tektites was too small to measure.

There is an application of the $B(i) = 0$ case to nuclides not found in nature that have known half-lives. Without justifying the assumption that none of the daughter was present initially, López de Azcona has computed an alleged lower limit to the time since the parent was formed (or since the system was separated from some other) (27). The value of this limit is based on the rather improbable assumption that $B(i) = 0$.

$A(i)$ known. In this case, Eq. 3 can be solved for *t*.

Libby's radiocarbon method of determining the time since an organic sample died (28) requires the initial C^{14} content to be taken as known and equal to the present C^{14} content of the C in living matter (29, 30). Cosmic-ray neutrons produce, from N^{14} in the upper atmosphere, C^{14} which becomes incorporated in all living matter. At death, the exchange with the atmosphere ceases, and the subsequent decay of the C^{14} permits age determinations within the past several thousand years. Many important dates have been determined in this way (31–35).

Knowledge of $A(i)$ permits age determination in the case of certain chemical sediments in which it is reasonable to assume that the concentration of radioactive parent now being deposited is the same as was being deposited at some earlier time because of the uniformity of the parent phase (e.g. ocean). Schlundt (36) has used the decay of Ra to date tufas in Yellowstone Park by this "per-cent-of-equilibrium" method. Piggot and Urry (37) used it to date core samples of marine sediments in which Io and Ra are selectively precipitated in amounts greater than would be in equilibrium with the U precipitated with them. The same method and data have been interpreted by Pettersson (38) as determining the rate of growth of the manganese nodules found in red clay.

$B(i)$ known and not zero. In this case age determination is possible by use of Eq. 4, 5, 6, or 7.

If a theory of element formation could predict initial abundances of such species as Pb^{206}, Pb^{207}, Pb^{208}, Ca^{40}, Sr^{87}, it would be possible to use this method to determine, from Eq. 4 or 6, the time elapsed since the cessation of the element-forming reactions.

A more useful method of finding the $B(i)$ needed for age determination is by analysis of more than a single sample; this is discussed below.

Two Phases

Consider an isolated system containing a nuclide *A* which decays with disintegration constant λ to form *B*, which is stable; let the parent and daughter have stable isotopes *A'* and *B'*, respectively; and let the system be separated at an initial instant, *i*, into phases 1 and 2. If the separation process does not separate isotpes, the isotope ratios at the time of separation will be the same in phase 1 as in phase 2, and

$$A_1(i)/A_1' = A_2(i)/A_2' \quad (10)$$
$$B_1(i)/B_1' = B_2(i)/B_2' \quad (11)$$

Since the considerations leading to Eqs. 3 and 4 are applicable to each phase separately, we have

$$A_1(t) = A_1(p)e^{\lambda t} \quad (12)$$
$$A_2(t) = A_2(p)e^{\lambda t} \quad (13)$$
$$B_1(p) - B_1(i) = A_1(p)(e^{\lambda t} - 1) \quad (14)$$
$$B_2(p) - B_2(i) = A_2(p)(e^{\lambda t} - 1) \quad (15)$$

Dividing Eq. 12 by Eq. 13, we have $A_1(t)/A_2(t) = A_1(p)/A_2(p)$, a constant independent of time, so that $A_1(t)/A_2(t) = A_1(i)/A_2(i)$, from which we find, using Eq. 10, that $A_1(t)/A_1' = A_2(t)/A_2'$.

Thus the isotopic constitution of the parent changes with time but is the same in both phases. Subsequent subdivision into other phases leaves the isotopic makeup of the parent identical in all phases, and independent of the time of separation. Nier (*39*) finds $U^{238}/U^{235} = 139$ for terrestrial sources from 10^8 to 10^9 years old. Brewer (*40*) finds that $Rb^{85}/Rb^{87} = 2.61$ for sources ranging from plants to old micas. Schumb, Evans, and Hastings (*41*) find identical isotopic compositions of terrestrial and meteoritic U, and conclude that their atoms must be of the same age. Schumb, Evans, and Leaders (*42*) and Suess (*43*) find the same K^{40} content for both meteoritic and terrestrial K.

One can conclude that element-forming reactions probably ceased simultaneously in the matter now composing the earth and the meteorites, or that they were separated simultaneously from an element factory, but not that they are of the same "age," since they may have separated from a parent body after element-forming reactions ceased in that body. Since the isotopic makeup of the parent is of little help in age determination, we shall neglect A'.

Eliminating $B_1(i)$ and $B_2(i)$ among Eqs. 11, 14, and 15, we have

$$\left(\frac{A_2(p)}{B_2'} - \frac{A_1(p)}{B_1'}\right)(e^{\lambda t} - 1) = \frac{B_2(p)}{B_2'} - \frac{B_1(p)}{B_1'} \qquad (16)$$

in which all the quantities are measurable except the age, t. This can be solved for t if $A_2(p)/B_2' - A_1(p)/B_1'$ and $B_2(p)/B_2' - B_1(p)/B_1'$ are not both zero. They will be nonzero if $A_1(i)/B_1' \neq A_2(i)/B_2'$, i.e. if the separation appreciably altered the relative concentrations of the elements in the two phases.

Alternatively, solution of Eqs. 11, 14, and 15 for $B_2(i)$, in terms of measurable abundances, gives

$$B_2(i) = B_2(p) \times \frac{B_1(p)/B_2(p) - A_1(p)/A_2(p)}{B_1'/B_2' - A_1(p)/A_2(p)} \qquad (17)$$

This shows that analyses of two separated phases permits the evaluation of $B(i)$ required for an age determination from Eq. 4, 5, 6, or 7.

Parent and daughter nuclides that occur in measurable quantities in both of any pair of phases that have been isolated ever since separation, could theoretically be used to determine age by this method. The phases of a meteorite or of a granite are examples. Analytical difficulties are so great that no such case occurs in the literature.

Festa and Santangelo (*44*) have given the equations for such a case. They tried to use them to find the age of the earth (or its crust) on the bases of the observed abundances of K^{40} and Ca^{40} in the earth's crust and in meteorites, and the assumption that the phase separation in meteorites took place at the same time as the separation of the earth's crust. The difference in isotopic composition of meteoritic and terrestrial Ca, required for this method, has not been observed. Hence the facts that the equations appear solvable for t, and that the result agrees with Holmes' value for the age of the earth's crust (*45*), are both arithmetical accidents (*46*).

Corrected ages. To determine "corrected" ages, regard the specimen as phase 2, the rest of the earth's crust as phase 1, and think of the sample as so much richer in parent A than is the rest of the earth's crust, that $A_1 \ll A_2$. In this case, $B_1(i) \simeq B_1(p)$, so that Eq. 11 or 17 becomes

$$B_2(i)/B_2' = B_1(p)/B_1' \qquad (18)$$

This equation states that the initial relative abundance of the daughter in the sample was the same as its present relative abundance in the earth's crust. Thus, for A-rich samples, one subtracts enough "common" daughter to leave only the radiogenic B, whose excess abundance is then the left side of Eq. 4, 5, 6, or 7.

In determining corrected Pb ages, Eq. 8 is used; the Pb now denotes the concentration of radiogenic Pb, i.e. total Pb minus enough common Pb to get rid of all the Pb^{204} (B'). This correction requires isotopic analysis of the Pb. Having an isotopic analysis of the Pb, there are really three independent methods of determining the age: from the $U^{238} \rightarrow Pb^{206}$, $U^{235} \rightarrow Pb^{207}$, and $Th^{232} \rightarrow Pb^{208}$ decay processes.

Because of the isotopy of the parents U^{238} and U^{235}, there is, for U-bearing minerals, a special method. If RaG is the atomic abundance of the radiogenic Pb^{206} (total Pb^{206} minus ordinary Pb), and AcD is the corresponding Pb^{207}, division of the Eq. 4 for U^{238} by that for U^{235} gives

$$\frac{RaG}{AcD} = \frac{U^{238}}{U^{235}} \frac{e^{\lambda_{U1}t} - 1}{e^{\lambda_{AcU}t} - 1} \qquad (19)$$

solvable for t without analysis of the specimen for U (*47, 48*). This method is less sensitive to alteration of the specimen through the loss of constituents than are the others (*48, 49*). Study of pleochroic halos is a useful analytical technique in this case, since one can use the relative darkenings of the RaC' and the An and AcC' alpha-particle halos to get the approximate RaG/AcD ratio directly, without the need of either chemical or isotopic analysis (*50*).

Considerable variation in the relative abundances of He^3 and He^4 has been observed (*17, 51*), but interpretation is not clear enough for calculation of corrected He ages. Something analogous to a corrected He age has been determined by Merkulova (*52*), who, using slightly elaborate assumptions, and argon rather than He^3 as a 'tracer,' showed, by means of the accumulation in the water of He that comes from the surrounding rock, that the waters of Matzesta are fossil, or as old as the rocks they fill.

Ahrens (*22, 23*) also subtracts the common daughter to determine ages from Rb^{87} decay.

The two decays of K^{40}, while applicable to determination of corrected ages, are poor for the purpose. The decay constants have only recently become approximately known (*53–56*). Use of the $K^{40} \rightarrow Ca^{40}$ decay is hampered because 97% of ordinary Ca is Ca^{40}, and the correction to radiogenic Ca is extremely sensitive to small errors in the isotopic analysis.

The $K^{40} \rightarrow A^{40}$ decay is unsatisfactory because so little is known of the geochemistry of argon. This decay has been used (*57*) to date salt deposits; isotopic analysis of the contained argon was used to correct for atmospheric argon. Aldrich and Nier (*58*) have also published data usable to determine an approximate corrected argon age, but the ages of their specimens were already known more accurately than they can be computed from the data.

Several authors have attempted to use the present quantity of atmospheric

argon in deriving estimates of the age of the earth, its crust, or its atmosphere. Jeffreys (*59*) used an obsolete decay-constant value. Tatel (*60*) discusses the highly inconclusive information that can be obtained this way; some of his work has been repeated, using less satisfactory data, by Chackett (*61*). Kulp (*62*) and Birch (*56*), showed that the A^{40} content of the atmosphere makes it reasonable to assume that the entire atmosphere, hydrosphere, and even the K necessary to account for continental granites on a basalt earth, may have been released from the interior of the earth during geologic history.

Other natural radioactive decay processes which might become useful are $La^{138} \rightarrow Ba^{138}$, $Nd^{150} \rightarrow Sm^{150}$, $Sm^{152} \rightarrow Nd^{148}$, $Lu^{176} \rightarrow Yb^{176}$, $Lu^{176} \rightarrow Hf^{176}$, and $Re^{187} \rightarrow Os^{187}$.

The "subtract-ordinary-daughter" method requires a mineral relatively rich in the parent. For many useful rocks and minerals, in which the parent concentration is of the same order as that in the earth's crust, Eq. 18 must be replaced by the more exact Eq. 17. For samples with an even smaller concentration of the parent, another method becomes applicable.

Parent-free phases. If a mineral contains essentially none of the parent, A, but appreciable quantities of the daughter, B, we can regard the isotopic composition of the daughter in the mineral as being that of the rock, magma, or ocean from which the mineral was separated, at the time of the separation, since no radiogenic daughter will have formed in it since. We can now divide Eq. 4 by B' and apply it to the parent phase

$$\frac{B(p)}{B'} = \frac{B(i)}{B'} + \frac{A(p)}{B'}(e^{\lambda t} - 1) \quad (20)$$

The present $B(p)/B'$ and $A(p)/B'$ are measurable in the ocean; the $B(i)/B'$ in the ocean at the time an A-free chemical sediment was precipitated is measurable now in the sediment; thus we can solve for t.

Wickman (*63*) proposes this method for age determination by means of the isotopic composition of the Sr or Pb in a marine chemical sediment; Walling (*64*) has considered Sr further.

This method has been applied by Voitkevich (*9*), who used Eq. 19, and regarded the earth's crust as parent phase. We find that the Pb now incorporated in the Ivigtut galena—the least "contaminated," i.e. oldest, of Nier's specimens (*65*)—was first separated from the rest of the earth's crust, and so from U and Th, about 3.1×10^9 years ago.

If we apply Eq. 20 to the interval between initial isolation of the parent phase, at instant i, and subsequent separation from it of an A-free mineral at instant m (p is reserved for the later present instant), we have

$$\frac{B(m)}{B'} = \frac{B(i)}{B'} + \frac{A(m)}{B'}(e^{\lambda t} - 1) \quad (21)$$

$B(m)/B'$ is measurable in the mineral now, but the other abundances are not known.

If t_0 is the age of the earth's sial crust (interval from i to p), and t_m that of the mineral (interval from m to p), then $t = t_0 - t_m$ and, from Eq. 3, Eq. 21 becomes

$$\frac{B(m)}{B'} = \frac{B(i)}{B'} + \frac{A(p)}{B'}(e^{\lambda t_0} - e^{\lambda t_m}) \quad (22)$$

Holmes (*45*) used this equation to show that the earth's sial crust was separated from the rest of the earth about 3.35×10^9 years ago. He used the data of Nier (*65, 66*) on the isotopic abundances of Pb in presumably U-free ores of known ages, t_m, to solve a set of Eqs. 22 for t_0. $B(i)/B'$ and t_0 were assumed the same for all samples; $B(m)/B'$ and t_m were known for each sample; $A(p)/B'$ was eliminated by dividing the equation for U^{238} by that for U^{235}, and using the known present ratio U^{238}/U^{235}.

Because of the possibility of multiple orogenies, Alpher and Herman (*67*) have questioned Holmes' accuracy. They put $B(i) = 0$ and derived only an upper limit to the age of the earth's crust.

Artificial radioelements. We turn now to methods that use parents unknown in nature but produced in the laboratory, and having known decay constants. Even if λ is so large that $A(p) = 0$ in both of two phases, the two phases could still have been separated from each other at a time before all the A had decayed. Thus the isotopic constitutions of the daughter could differ in the two phases, and we have the inequality

$$B_1(p)/B_1' \neq B_2(p)/B_2' \quad (23)$$

Any present excess of B in one phase must, at the time of phase separation, have been an excess of A in that phase. The quantities in Eq. 23 are measurable, and can be inserted in Eq. 16. The present abundances of A are not measurable, but are known to be less than the experimentally detectable minimum; their difference is also less than a known quantity. Thus, Eq. 16 would permit solution for a lower limit to the time since separation, if any case of this kind were known.

The possible observation of excess Xe^{129} resulting from I^{129} decay has been reported by Ingram and Reynolds (*68*), but the data cannot be interpreted easily. The only cases in which isotopic-abundance variations have been reliably observed are for the products of known natural radioelements and for light elements capable of undergoing some isotope separation in natural geochemical or physiological processes. It might be of interest to reexamine, for possible variation from sample to sample, the isotopic abundances of Ba, Xe, Ag, Ru, A, and B, since they have isotopes which are decay products of reasonably long-lived artificial nuclides.

If the isotopic constitution of the daughter is different in two phases, and the total masses of the two separate phases can be estimated, an upper limit to the time between isolation of the parent system and its separation into two phases can be given. The present excess of B in one phase is a lower limit to the amount of A present in the parent at the time of phase separation, and the present total amount of B in both phases is an upper limit to the amount of A present in the parent at the time of its isolation. These two limits determine an upper limit to the time between the two events.

Even when the two members of Eq. 23 are equal, some information may still be obtained. Suess (*8*) uses the observed constancy of the isotopic makeup of the daughter in various sources, together with certain rules relative to the initial abundance of the parent, to show that about 10^9 years, or more, must have intervened between formation of the elements (or separation of the earth from an element factory) and geochemical separation of the different portions of the earth that can be sampled. Brown (*69*) had suggested use of the same method in connection with meteorites.

Using assumed initial abundances of I^{129} and Xe^{129}, Katcoff, Schaeffer, and Hastings (*70*) attempted to derive a lower limit to the time between element

formation and formation of the atmosphere. This limit, as revised by Suess and Brown (*71*), is about 0.4×10^9 years.

Assumptions

This treatment has been, to a considerable extent, an idealization. Application requires detailed consideration of the effects of failure to satisfy the assumptions made.

Perhaps the most unrealistic was the assumption that geologic and cosmic processes could be regarded as a series of events separated by intervals during which the systems remained isolated from one another.

The meaning of the term "age" is rather unclear, at least for metamorphic rocks and mechanical sediments. For an igneous rock or a chemical sediment, we hope to find the time back to its crystallization, a process which may have taken place in so short a time as to be regarded as an event. But has the rock been isolated since then? Age determination methods require that the sample has neither gained nor lost any of the parent, daughter, or intermediate element. Geochemical studies have attempted to select, for each method, the minerals least likely to have changed. Guimarães (*72*) commends monazite as the best U mineral. For the He method, magnetite appears to be best (*18*). The RaG/AcD method is less affected (*48, 49*) by alteration of the mineral than are the parent-to-daughter-ratio methods.

Even when no leaching or other alteration has taken place the samples have not been isolated from the effects of cosmic-ray reactions. The effects of cosmic rays in producing both isotopes of He have been considered by Morrison and Beard (*73*) and Huntley (*16*). Bauer (*20*) regards the He in meteorites as having this origin, so that Paneth's determinations of meteorite ages (*19*) would be invalidated. Lewis (*74*) suggested that the earth's crust was formed by cosmic ray action on an Fe-Ni core. Although the effect of cosmic rays on abundances of elements used in age determination is not that great, it should be considered. Brajnikov (*75*) suggests the fission of U by neutrons of cosmic-ray or terrestrial origin as a possible source of error in Pb ages.

Another questionable assumption is that the material from which the sample was formed was of the same isotopic makeup as the average for the whole crust of the earth. Actually the parent material may have had a complex history of isolation, remelting, contamination, reseparation, etc. Thus even in specimens unaltered since their last crystallizations, the isotopic constitution of an element having radiogenic isotopes might be characteristic of an age anywhere between that since the last isolation, and that since the material first solidified from a fluid outer shell of the earth.

When U or Th is the parent element the methods require the assumption that the sample contained, at the time of its isolation, no nonequilibrium amounts of any radioelements intermediate between parent and the end product, Pb. There exist minerals for which this is not true as proven by Henderson's discovery of "fossil" pleochroic halos (*76*) that correspond to decay of hydrothermally deposited intermediates, by Schlundt's work on the Ra content of Yellowstone tufas (*36*), and by the work of Piggot and Urry (*37*) and Pettersson (*38*) on deep sea sediments. Barium and Th minerals may be a bit dubious because of the possible presence, at the time of formation, of nonequilibrium amounts of Ra and Io, respectively.

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A Multicurie Irradiation Site for Exposure of Large Animals to Whole-Body Gamma Irradiation

Reasonably uniform whole-body gamma irradiation of untethered large animals at about 40 r/hr is possible in the outdoor exposure field described. The time-intensity relationship is flexible, and either laboratory or domestic animals can be used

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FIG. 2. Charge site showing quadropod exclusion fence, cable, and cistern cover

FOR A NUMBER of years, much effort has been expended in studying the pathologic physiology of whole-body irradiation in the lethal and sublethal dose ranges. Except for relatively few studies with the pig, most of this work has been done with small laboratory animals ranging in size from the mouse to the dog. The primary interest in this research is the effect of irradiation upon humans, but the interpretation and extrapolation of these data on small animals as they relate to humans have certain serious limitations.

It seems necessary, therefore, to have information on animals with (a) a body volume more nearly approximating that of man, (b) stress on body organs and appendages more comparable to those of man, and (c) a longer life expectancy than small laboratory animals. It is also advisable to use an animal in which detailed studies can be made of clinical changes that occur following irradiation.

This consideration led to the design and construction of the exposure device described here. It is an exposure field in which radioisotopes are used and by means of which several large animals at a time can be exposed to external whole-body irradiation. The Western burro, *Equus asinus asinus*, was the first test animal so exposed, but the field can accommodate animals in size up to horses and cattle. Caged small animals could, of course, be accommodated with no difficulty.

Basic Requirements

For practical operation and maximum usefulness, the exposure field had to fulfill these basic requirements: It had to

1. Be reasonable in cost.

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FIG. 1. General view of animal exposure field showing earth barrier, control house at right, and incompleted observation post beyond the house. Note cables running from individual charge sites to control house

2. Be capable of operation with safety for personnel at all times.

3. Be capable of activation and deactivation with ease.

4. Allow for the variation of time-intensity ratios at will.

5. Provide, with relative ease, for changing the radioactive sources to vary the energy spectrum.

6. Permit several untethered animals to be exposed simultaneously with only moderate variation in dose.

7. Have facilities for feeding and watering the animals during prolonged exposure.

8. Provide for safe observation of the animals during exposure.

The Design

Using earth as a natural shield and exposing the animals in the open eliminated the cost of a large amount of housing. Housing was not a necessity because the large animals that were to be exposed were customarily kept outdoors, and local housing could easily be furnished, as needed, when caged laboratory animals were to be used.

A natural amphitheater was selected in the restricted Oak Ridge area that furnished shielding from three sides with a minimum of expense in moving earth. The fourth side was open to an unused ravine and wooded area. See Fig. 1.

A barn for feeding and observing the animals after exposure was constructed about 400 yards from the exposure field behind natural shielding.

The entire operating area is surrounded by a security fence placed at such a distance that the rate at the fence does not exceed 3 mr/hour when the field is in full operation. There are appropriate warning signs at intervals along the fence and upon the one gate to the area.

In basic design, the field consists of a circular concrete pad, 50 ft in diameter, with 19 locations for the radioactive sources distributed in a hexagonal pattern. An area, $2\frac{1}{2}$ ft in radius, surrounds each charge site from which the animals are excluded by means of a fence. Certain peripheral areas which have a lower photon flux than acceptable are fenced off and, in four cases, are used to hold watering troughs.

The ideal arrangement to produce an area of uniform radioactivity would be to have an infinite number of locations for the radioactive charges. However, calculations indicated that the only practical approach was to utilize a system of fencing off areas that were too high or too low in photon flux. The best compromise appeared to be the arrangement of 19 charges with the exclusion circles described, which, in addition, would eliminate the possibility of damage to the charge by the animal.

The method for activation and deactivation of the field represented an important problem. The solution of choice was an arrangement whereby the field would be deactivated when

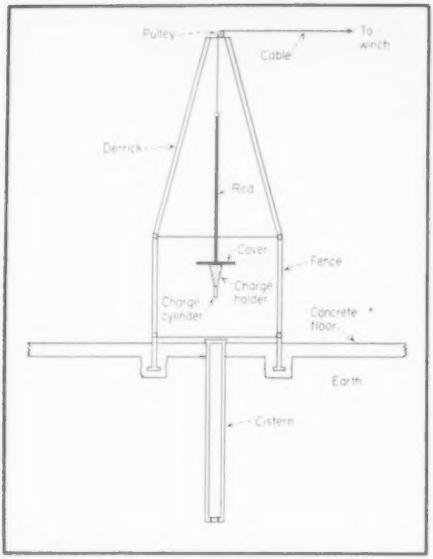

FIG. 3. Sectional diagram of the radioactive charge assembly

FIG. 4. Sugarman carrier being monitored. Note the charge holder and adapter

the radioactive charges were lowered into water-filled cisterns. An individual, manually operated cable and winch for each source was selected as the simplest and most reliable means for raising and lowering the charge.

As seen in Figs. 2 and 3, a derrick or quadropod covers each charge location, beneath which is a cast-iron pipe cistern filled with water. The cisterns, 7 ft deep, are double lined with a removable watertight sleeve, 5 in. in diameter, inside an outer pipe which is 8 in. in diameter. Both the sleeve and outer pipe have caps that are soldered at the base so as to be watertight. This arrangement prevents contamination of the ground-water supply in the event of fracture of the charge holder and leakage of radioactivity into the cistern water.

A 6-ft rod, which runs through a cast-iron plate, is suspended from the stainless-steel cable. As shown in Fig. 3, the radioactive charge is attached to the end of the rod. The cast-iron plate covers the cistern. It serves to trip a limit switch when in place and limits the depth (almost 7 ft) to which the charge can be lowered.

The charge holder is a stainless-steel cone, filled with lead. The weight of the lead holds the cable taut, minimizes wind sway, and aids in lowering the charge. It provides shielding as well.

Since the charge is always lowered to the bottom of the cistern, which is kept filled with water for additional shielding, the actual shielding for anyone standing directly above the lowered charge is 6 ft of water plus 1 ft of lead.

The stainless-steel cables carrying the charges are run over pulleys from the quadropods to winches located in a control house nearby. This house has 1-ft concrete walls and roof, and was built, for safety purposes, with an earth barrier of about 15 ft interposed between it and the exposure field. A panel in the control house shows a signal light for each of the 19 charge locations. The light is on only when the charge is in the cistern.

To observe the animals at intervals with a minimum of exposure to personnel, a 2-ft concrete barrier was constructed on a cliff overlooking the exposure field. The barrier is about 50 ft from the edge of the field. An 8-in. block of lead glass, through which the entire field is visible, is built into the concrete wall. This observation post is invaluable in the loading and unloading operations. These structures and their relationships are seen in Fig. 1.

To provide safe access and egress from the exposure field area, the control house, and the observation post, there are defiles or cuts so designed that at all times there is adequate earth shielding between the personnel and the field. There is also a flag pole equipped with a red blinker light near the field. A flag is raised and the light turned on when the field is activated. This makes it possible to tell the status of the field from the beginning of the approach road about 600 yards away.

A fencing arrangement near the control house and the entrance to the field itself prevents personnel from getting in the line of sight of the radiation unless they consciously open a labeled gate.

Loading and Unloading

Perhaps the greatest opportunity for exposure of personnel to above-tolerance amounts of radiation occurs during the loading or unloading of the field with the radioactive charges. The actual operation as performed is described below:

Tantalum-182 was employed as the initial radioactive source. Approximately one pound of stable tantalum pellets was placed in each of 19 alumi-

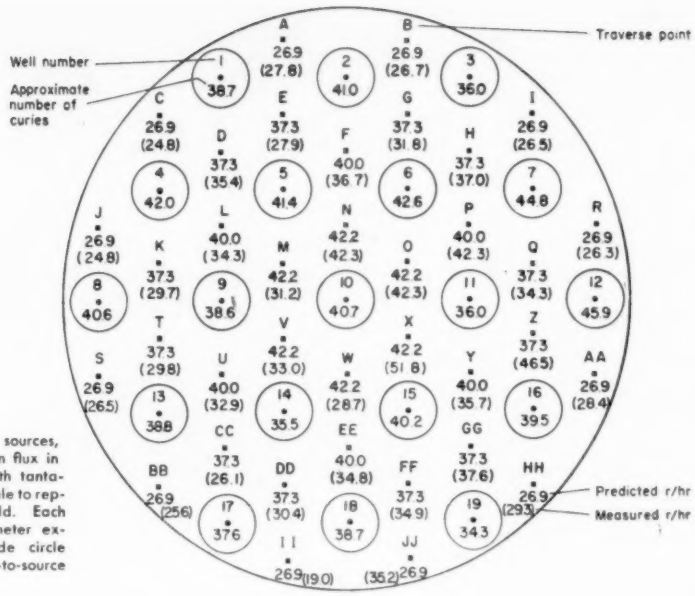

FIG. 5. Distribution of sources, curie values, and radiation flux in exposure field loaded with tantalum-182. Drawing is to scale to represent 50-ft-diameter field. Each circle represents 5-ft-diameter exclusion fence. Point inside circle represents source. Source-to-source distance is 11 ft

num cylinders, 1 in. in diameter and 4½ in. long with a wall thickness of 1/16 in. These cylinders were activated in the reactor of the Oak Ridge National Laboratory to produce about 40 curies of radioactivity per cylinder.

Personnel at the Oak Ridge National Laboratory attached the activated cylinders to the charge holder which was subsequently to become an integral part of the exposure device as already described. The charge holder and cylinder were then placed in a Sugarman carrier which had been provided with an adapter sleeve to receive it. See Fig. 4. At this time the source was completely shielded and was transported by truck to the exposure field.

At the field the Sugarman carrier was transferred to a dolly which was wheeled and centered over a cistern. Without opening the carrier or exposing personnel in anyway, the charge holder assembly was screwed onto the rod attached to the cable. A block and tackle were attached to the dolly so the latter could be moved by personnel from a protected vantage point at the proper time. All personnel were then cleared from the exposure field and were located behind the observation barrier, in the control house, and at the protected vantage point; these locations were in telephonic communication and the operation was directed from the observation post.

The operator in the control house lifted the charge assembly from the Sugarman carrier by means of the winch; at this time the source was fully exposed. The dolly and Sugarman carrier were then removed from over the cistern by means of the block and tackle operated from the protected vantage point. When the charge assembly was free and motionless, it was lowered slowly into the cistern and became completely shielded. It was then safe for personnel to return to the exposure field.

This operation was repeated at each of the other eighteen charge sites. The first complete charging of the field was accomplished in less than three days, most of the time being spent in trucking the carriers between the Oak Ridge National Laboratory and the exposure field.

The unloading operation was carried out according to the same principles, but in reverse. It was a little more difficult to get the charge assembly properly seated within the Sugarman carrier; to aid in this operation, wires were attached to the rod and cable which were operated from a distance to guide the charge assembly.

The adequacy of the whole procedure is indicated by the fact that no personnel received the maximum permissible exposure during the entire operation.

Measurements in the Field

In the case of the tantalum sources, it had been calculated that approximately 40 curies of activity at each charge site would provide the desired dose rate within the field.

The results of actual measurements are shown in Fig. 5, which represents the geometrical pattern of charge sites in the field. The upper numeral in the circle represents the well number or the number of the charge site. The number directly below it represents the number of curies in the individual source determined as follows: The probe of a radiac set* was placed at a measured distance, usually about 70 cm, from the center of the charge site. This set had previously been calibrated against a 100-curie source.

The individual source was raised to be directly in line with the probe and

*Some of the radiac instrumentation used on this project was supplied by the Signal Corps, U. S. Army.

the reading in r/hr was made. The equation used to calculate the number of curies was $r = \frac{6CE}{d^2}$, where r = roentgens per hour, C = curies, E = gamma energy in million electron volts, and d = distance in feet.

As may be noted, the number of curies in each source was in fair agreement with the anticipated value.

The dots outside the well circles represent the geometrical location within the field and are designated by letter. The value in r/hr below the dot was calculated by summation of the contributions of every source in the field, as determined from the curie value, to that point. The values in parentheses are the measured dose rates.

Detailed studies were made at numerous locations within the field to obtain a measure of the homogeneity of the radiation flux. To facilitate this measurement, a cart was designed to carry the instruments which can be moved by remote control from place to place within the field. The dosimeters on the cart can be adjusted in a vertical position also by remote control. This eliminates the necessity of complete deactivation of the field between individual measurements.

Exposure of Animals

A description of an actual experiment performed in the field follows to illustrate its usefulness.

Ten burros were selected to be exposed at a time. Surcingles with a pocket on each side were strapped to the animals over the withers, as shown in Fig. 6. Victoreen thimble chambers (1,000 r) were enclosed in a rubber casing for protection against humidity and were placed in the pockets. The animals were then turned into the exposure field (see photograph on front cover), and the sources were raised for an exposure period of 16 hours. The height to which the sources are raised depends on the experiment. In this particular study, the sources were raised to a height of 1 meter above the cisterns, which is about the mid-height of the burro body.

The table on this page presents the values of dosage received, as measured by the Victoreen chambers. These values give an indication of the uniformity of irradiation received between animals and between the two measurements on each animal.

FIG. 6. Burro with a surcingle-containing two Victoreen thimble chambers, one on each side. Each chamber can measure up to 1,000 roentgens

Dosimetry Data on 10 Burros Exposed to Whole-Body Gamma Radiation for 16 Hours

	Chamber reading total roentgens	
Burro No.	*Dosimeter on left side*	*Dosimeter on right side*
16	630	560
146	520	590
32	530	520
223	540	560
203	560	660
124	540	520
23	500	440
235	620	560
83	530	590
59	520	620
Average	549	562

Discussion

On the basis of experience to date, it is apparent that the exposure field is entirely adequate to serve the purposes for which it was designed. The cost of construction is considered to be reasonable, especially when compared with costs for other types of installations which can be used for similar purposes.

The maximum number of animals which can be exposed at any one time is actually determined by the amount of self-shielding. About 40 animals could be crowded onto the pad at one time, but there would be so much self-shielding under these conditions that the dose received by the individual animals would be too variable for the usual test purposes.

The field has been operated for several months with only one occasion of exposure of personnel near the maximum permissible dose. This exposure resulted from the fact that in the original design the charges were attached to the charge holder by a spring clip device. During the operation of the field two charges became disengaged and fell into the cisterns; the process of recovering and reattaching them to the charge holder presented considerable difficulty. Since that time, charges have been securely attached to the charge holders by a screw arrangement.

Some 105 animals have already been exposed, without tethering, and received a reasonably uniform dosage as indicated by actual measurement. Animals have been kept on the field for as long as 39 hours with replenishment of feed and water during short periods of deactivation.

* * *

The authors wish to thank Dr. C. L. Comar, Laboratory Director and Research Coordinator, for his constant advice and guidance in this project.

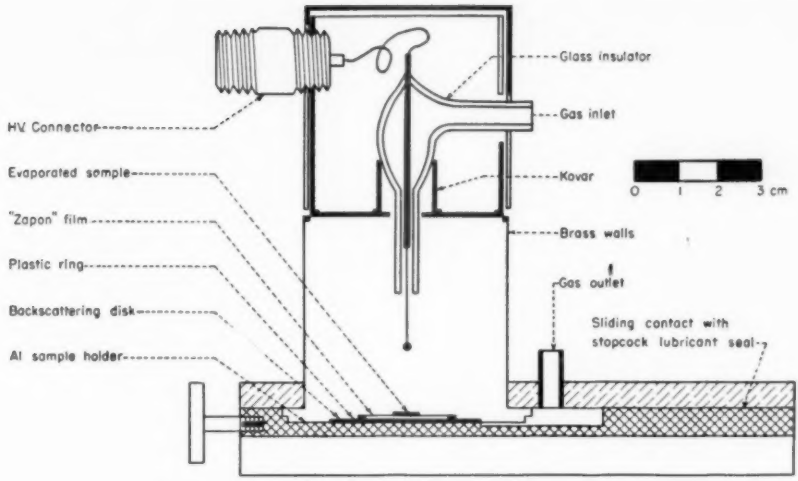

FIG. 1. Experimental arrangement of windowless G-M counter

Backscattering of Beta Rays in Windowless G-M Counters

Absolute disintegration rates can be determined in a windowless counter only if the backscattering factor is known. This factor has been found experimentally by using various backscatterers that were thick enough to give a limiting maximum value

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WINDOWLESS, gas-flow Geiger-Müller counters are particularly useful in the detection of low-energy beta particles since absorption by the window and air are eliminated. As Graf, Comar and Whitney (*1*) have shown, the lower the beta energy to be measured, the greater will be the advantage of a windowless counter over the conventional end-window counter. A counter tube operating in the Geiger region gives nearly uniform pulses which are independent of the primary ionization. Thus a pulse may be initiated by a scattered beta particle although it produces but a single ion pair in the counter gas.

In this investigation counting rates corresponding to nearly 80% of the radioactive disintegration rates were sometimes obtained when beta emitters were introduced into a windowless G-M counter. Quite evidently, scattering is important in the attainment of such high counting efficiencies. With conventional thin end-window counters (about 2 mg/cm² thick), efficiencies are usually no more than 10–15%. In contrast to other counting arrangements, the counting rates obtained in windowless counters are remarkably insensitive to the precise geometrical arrangement of the source,

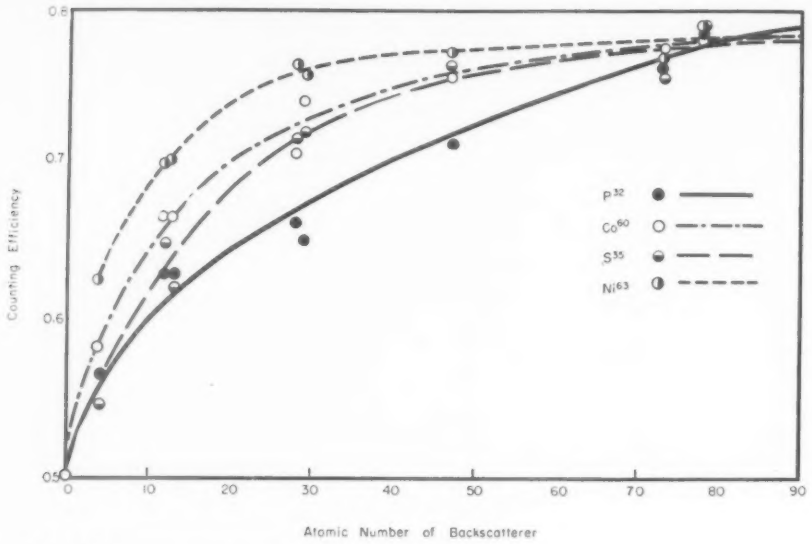

FIG. 2. Backscattering curves for windowless G-M counter

so little attention need be given to attaining an exactly reproducible placement of the source.

The windowless G-M counter also offers some advantage over the corresponding proportional counter which requires more extensive electronic amplification with an arbitrary and not too reproducible discrimination.

Before absolute disintegration rates can be determined in a windowless counter, a knowledge of the backscattering factor is necessary. Since no such data have been reported for the windowless G-M counter, the backscattering for four beta emitters by backing elements of various atomic numbers was investigated. For an end-window counter, the counting rate of a nearly weightless source on a thin plastic film can be used as the value for zero backscatterer. This value can then be compared with the counting rates resulting from placing the backscatterers directly behind the source. However, in a windowless flow counter, one cannot obtain the counting rate for zero backscatterer in this manner since the sample must always be placed directly on top of the base of the counter chamber.

A comparison has been made of the counting rates obtained in a windowless G-M counter by placing radioactive deposits on various backscatterers that were thick enough to give a limiting maximum value. (Engelkemeir and co-workers (2) have shown that a thickness greater than ⅓ of the beta-particle range suffices to give the maximum or saturation effect.) One-half the absolute disintegration rate of the samples, if known, was used as the value for zero backscatterer. From the variation of the counting rate with atomic number of the backscatterer, curves of counting efficiency versus atomic number were plotted for each beta emitter investigated.

Experimental Procedure

In this work a one-place windowless, gas-flow G-M counter manufactured by the N. Wood Co., Chicago, Ill., was used. This counter is shown in Fig. 1. It was operated at about 1,300 volts. "Q" gas obtained from the Nuclear Instrument and Chemical Corp., Chicago, Ill., was passed through the counter at a constant rate. A conventional scale-of-64 scaler was used.

Activities used. Four different beta emitters were used to indicate variations which might be due to the beta-ray energies and possibly to the differences in the spectra. The table lists the pertinent data.

Materials used as backscatterers. Beryllium, magnesium, aluminum, nickel, copper, silver, tantalum and platinum metals were used as the backscattering elements. Disks about 2.5 cm in diameter and thick enough to insure saturation backscattering were used. Surfaces of the various metals had different characteristics; for example, the platinum was bright while the tantalum was quite dull.

All disks except the beryllium were cut from commercial foils which were probably fabricated by rolling. The beryllium disks (X-ray windows) appeared to have been cut by an abrasive wheel from rod. The magnesium disks were etched with dilute HCl to remove oxide film.

Disintegration-rate calibrations. P^{32} samples were calibrated by comparison of counting rates with aliquots of a standard sample received from the National Bureau of Standards in April, 1951. The disintegration rates of Co^{60} samples were obtained by comparison of their counting rates with a standard source which had been calibrated in this laboratory by the coincidence-counting technique. The disintegration rate of the P^{32} standard was also calculated from a comparison of its counting rate with that of the Co^{60} standard with appropriate corrections for the energy dependence of absorption and scattering.

A value 1.07 times the value taken from the National Bureau of Standards

data was obtained. Both B. P. Burtt (*3*) and T. Novey (*4*) have reported obtaining values 8% higher for the absolute disintegration rate of P^{32} standards than the values given by the National Bureau of Standards. They suggested that the National Bureau of Standards value might be in error by 8% because of self-scattering due to the finite thickness of the RaD-RaE standards which were used.

Preparation of samples. In exploratory experiments, 50-μl aliquots of the various active solutions were evaporated directly on the metal backscatterers. Two samples of each were prepared and counted. Yaffe (*5*) has reported that surface differences can influence counting rates. Consequently, in a second series of experiments the samples were prepared by evaporation of 50-μl aliquots of the activities on thin Zapon films of about 30 $\mu g/cm^2$ thickness. The films were supported 1.0 mm above the surface of the metal backing by plastic rings 2.5 cm in diameter. The samples faced the sensitive volume of the counter.

Results and Discussion

The results from the samples evaporated directly on the metals proved to be very erratic for Ni^{63} and S^{35}. These erratic results may have been partially due to differences in the metal surfaces. The principal causes were probably the attack of the metals by the very dilute acid solutions with subsequent absorption of the radiation or an uneven distribution of the activity on the backscatterer with resulting differences in self-absorption. All of these factors would be more important for the lower-energy beta emitters. However, the fact that tantalum consistently gave values which appeared slightly low in comparison to platinum and the other metals, may have been due to differences in the metal surface character.

The experimental results of the film experiments are shown in Fig. 2. Some of the scattering of the observed points may be due to fluctuations in the efficiency of the counter itself. Changes in atmospheric pressure and temperature may cause alterations in its counting characteristics. For Co^{60} and P^{32} samples, one-half the absolute disintegration rate was taken as the counting rate for a backscatterer of zero atomic number. (The National Bureau of Standards value of the disintegration rate for P^{32} was used.) With Co^{60}, the counting efficiency approached a limiting value of about 78% for platinum backing ($Z = 78$). The counting efficiency for P^{32} attained a similar value for platinum backing, and it seems unlikely that much higher counting rates would be obtained with heavier elements.

Differences between the Co^{60} and S^{35} curves were too small to be real. However, the counting efficiency for Ni^{63} approached a saturation value at significantly lower atomic numbers. From the shape of the curve there seems to be little doubt that the saturation value must be about 75–80%. Consequently, the counting data in Fig. 2 for S^{35} and Ni^{63} have been converted to efficiencies by setting their saturation values equal to 78%.

Counting efficiencies for thin radioactive samples may therefore be read directly from Fig. 2. Of particular value is the feature that, with heavy element backings—platinum or tantalum—counting rates for thin samples in windowless counters are independent of the beta-ray energy over a wide range. Therefore, under these conditions disintegration rates can be taken as proportional to counting rates.

Characteristics of Beta Emitters

Activity	$T_{1/2}$	$E_{max.}$ *of* β^- *(Mev)*	*Specific Activity (dpm/mg)*	*Chemical Form*	*Source*
Ni^{63}	85y	0.067	5.3×10^8 ($50\mu l = 0.01\mu g$)	$NiCl_2$	Oak Ridge Pile $Ni(n,\gamma)$
S^{35}	87d	0.17	no carrier ($50\mu l = 0.00\mu g$)	H_2SO_4	Oak Ridge Pile $Cl(n,p)$
Co^{60}	5.3y	0.31	5×10^7 ($50\mu l = 0.15\mu g$)	$CoCl_2$	Oak Ridge Pile $Co(n,\gamma)$
P^{32}	14.3d	1.7	4.2×10^8 ($50\mu l = 0.02\mu g$)	H_3PO_4	National Bureau of Standards $S(n,p)$

* * *

Contribution No. 179 from the Institute for Atomic Research and Department of Chemistry, Iowa State College, Ames, Iowa. This work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.

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SPECIAL REPORT IN JUNE

From 1943 until the present, more than $6½-billion have been spent on atomic energy development. But because of the veil of secrecy surrounding the program, it has been almost impossible to get a clear picture of how this money has been spent.

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Look for this special report in the June issue of NUCLEONICS.

MOBILE Radiochemical Laboratory

By J. KOHL and R. L. NEWACHECK
Engineering Department, Tracerlab, Inc.
Western Division, Berkeley, California

FACILITIES for chemical analysis, sample preparation, and radioactivity counting of samples are included in a 22-ft trailer designed by Tracerlab, Inc., for the Department of Defense. This mobile laboratory, which also carries its own utilities, makes possible field measurements and evaluations of radioactivity that are impossible with ordinary portable instruments.

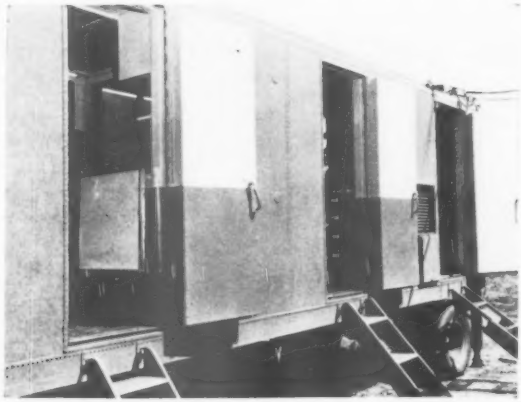
The trailer is divided into three rooms, each 87 in. wide and 75 in. high. The utility room is 74 in. long, the chemistry laboratory 90 in. long, and the counting room 76 in. long. The last two rooms are joined by a sliding door.

Thermostat-controlled air conditioning and heating are both provided. The ventilating ducts have been designed so that for cooling, air is supplied at the ceiling, and for heating, warm air is supplied at floor level.

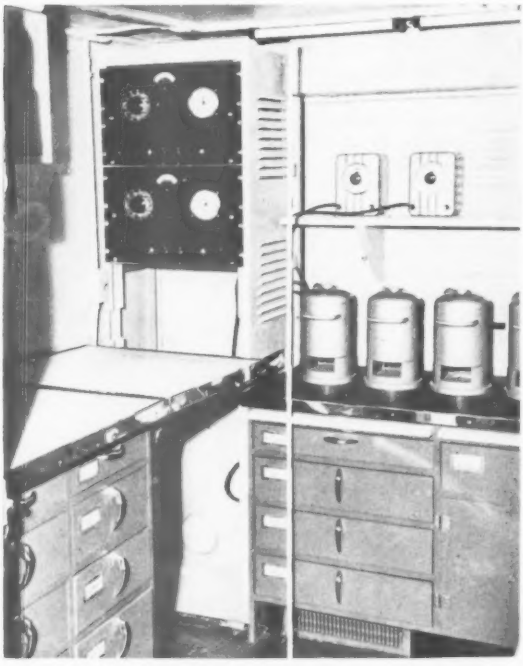
The trailer laboratory was designed and constructed by the Western Division of Tracerlab, Inc., at Berkeley, California. Earl Sherman and Co. sub-contracted the trailer body work, while Aladdin Blower Corp. manufactured the ventilating ducts, hoods, and the stainless-steel laboratory bench. The complete laboratory, including the trailer and all equipment, cost about $70,000.

* * *

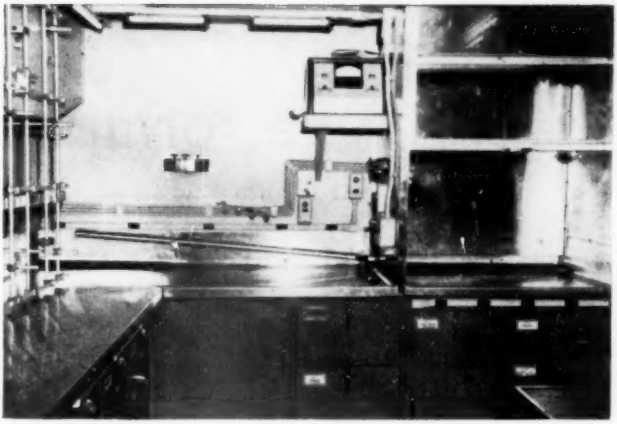
Assistance in the design was obtained from R. D. Zentner and other radiochemists of this firm, and from R. A. Weiss, L. R. Tipton, and C. L. Blair of the Nucleonics Branch, Evans Signal Laboratory, Belmar, New Jersey.



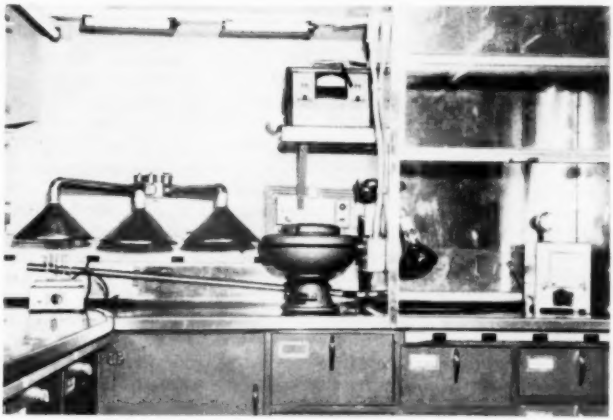
1 DIVIDED into three rooms, 22-ft four-wheel trailer constructed for radar work has been transformed into radiochemical laboratory. From left to right, doors open into counting room, chemistry laboratory, and utility room. Utility room, accessible only from the outside, contains a 12½-kva motor-generator set, a gasoline space heater, hood blowers, air compressor, vacuum pump, and a 60-gal water tank. Acetylene tank, gasoline tank, and 1½-ton air conditioning unit are mounted behind swinging doors on front of trailer



2 IN COUNTING ROOM, electronic equipment is rack mounted to save space; cooling air is supplied behind racks. Besides scalers shown, equipment includes three other scalers, a pulse amplifier, counting-rate meter, strip-chart recorder, and crystal-type frequency-regulated power supply for the timers. The 100-lb shielded sample holders are bolted to the Masonite bench at right. Transite-covered bench at left provides space for electrical repairs. Lumline lighting minimizes interference with counting†



3 HOOD, splashboard, and working areas in chemistry laboratory are fabricated of type-316 stainless steel for corrosion resistance. Main hood has two-speed blower and baffles set to provide minimum air flow of 100 ft/min. Fresh-air inlet at front of hood minimizes loss of heated or cooled air from trailer. Infrared lamp is provided for heating, and utilities are controlled from outside of hood. Monitor is permanently mounted alongside the hood



4 AUXILIARY HOODS can be plugged in when needed. Made of two concentric cones, they provide rising curtain of air around hot plate during evaporations. Troughs collect condensation, carry it to outside drain. Stainless-steel sink (not shown) has foot-operated valves and water demineralizer. Locked drawers and cabinets are used to store equipment, with balance, centrifuge, and muffle furnace mounted in shock-proof boxes

5 GLASSWARE is carried in sponge-rubber mounts to prevent breakage. Clips prevent flasks from jarring loose. Laboratory reagents are stored in glass or polyethylene bottles. These are placed in Tygon-coated cans that retain liquids in case of bottle breakage

Performance of Pulsed

When short time of operation is not a limitation, pulsed scintillation counters can be used to obtain exceedingly short resolving times with high amplification and current output from the photomultiplier. Results of pulsed operation are used to calculate photomultiplier time-dispersion effects

At Stanford University, the use of pulsed photomultipliers in high-speed scintillation counter systems, first reported in 1950 (*1*), was motivated by the necessity of developing high-resolution counting equipment for use with the Stanford linear electron accelerators. These machines operate with a beam pulse of only one microsecond duration. Although the techniques developed are of limited applicability, the practicability of pulsed operation was demonstrated, and an efficient coincidence counting system with exceedingly short resolving time was developed. As by-products of the investigation, improved results on time-dispersion effects in photomultipliers of the 931A and 1P21 types were obtained, and direct measurements of the fluorescence decay time of certain scintillators were made.

Advantages of Pulsed Operation

The three most important operating characteristics of a photomultiplier for use in a high-resolution counting system are amplification, peak output current, and small time-dispersion of the amplified pulses. All three of these characteristics are improved by higher voltage operation of a photomultiplier, up to that voltage per stage at which the secondary-emission multiplication of the surfaces reaches its maximum value.

An approximate plot of the secondary multiplication versus voltage per stage, for surfaces of the type used in the 931A and 1P21 multipliers, is shown in Fig. 1. At ordinary operating voltages (about 1 kv total voltage or 100 volts per stage), the multiplication per stage is approximately 4, so that the amplification of a 9-stage multiplier is around 500,000. However, at 450 volts per stage, or about 4 kv total voltage, the multiplication has risen to 10 per stage, increasing the total amplification to 10^9.

With d-c operation such high voltages are inaccessible, owing to regenerative ionization effects within the tube. These cause excessive noise and, eventually, voltage breakdown. If ionization effects constitute the dominant limitation on operating voltage, pulsed operation can effectively remove this limitation, since if a sufficiently short pulsing time is used, advantage can be taken of the low mobility of ions relative to electrons. In such a case, operation at the optimum voltage described previously may be possible. The price that is paid is that as higher and higher over-voltages are imposed, shorter and shorter pulses must be used to prevent breakdown. At the highest voltages used in these experiments (4 to 5 kv) the pulse length had to be reduced to 2.5 μsec or less.

General Techniques

In almost all of the experiments, multipliers of the 931A and 1P21 types were used, these being the most satisfactory from the standpoint of speed and freedom from breakdown effects. Pulses were applied from a voltage-regulated high-voltage pulser. Regulation was, of course, not of great importance when the multipliers were operated at the peak of the secondary-emission curve.

The pulser was capable of delivering pulses with a duration up to about 3 μsec with an amplitude up to 5 kv into a 300-ohm load, and with a repetition rate of a few hundred cycles per second. Dividers with 100-ohm resistors were used, so that the total divider impedance was 1,000 ohms. Thus three multipliers could simultaneously be pulsed to the full pulser voltage, or more than three at reduced voltages.

Breakdown of tubes. It was soon observed that there is a great range of variability in the breakdown characteristics of different tubes when pulsed. This is probably associated with individual differences in the residual gas pressure in the tubes and, occasionally, with the presence of field emission from sharp edges of the tube elements. Tubes falling in the first category, where voltage breakdown was attributable primarily to ion effects, showed a characteristic time lag in the breakdown when the output pulses were displayed on an oscilloscope screen. A few of the tubes tried were usable upon first operation. Others, which showed violent ion-induced breakdown at first, could be "sparked in" by pulsing under violent breakdown conditions for a few hours, after which time they operated successfully without breakdown up to normal pulse operating voltages (4 kv). With the low repetition rate which was used (60 cps), no apparent damage was done to the sensitized surfaces by such processing.

As a result of the testing and processing of a group of unselected 931A and 1P21 tubes, it was found that perhaps

Photomultipliers

By R. F. POST*
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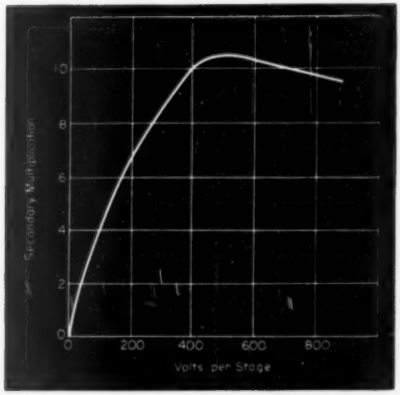

FIG. 1. Variation of secondary multiplication with voltage for 931A and 1P21 type surfaces

10 to 20% of the 931A tubes, and a somewhat higher percentage of the 1P21 tubes, could be made to perform well in pulsed service. Of the group of tubes which were usable, a few were exceptional, giving very large output pulses and infrequent noise counts.

Some of the multipliers which could not be used could be seen to be limited primarily by field-emission effects of a type which were not improved by pulse processing. These tubes were not usable at voltages appreciably above the d-c voltage limit. In all of the tests a close-fitting metal shield electrically connected to the photocathode was used. This was found to be particularly helpful.

Circuit construction. It was found that it is important to observe good high-frequency practice carefully in making the signal output connections to the multiplier. In those experiments where the greatest speed of response was required, the base of the multiplier tube was removed, and the shortest possible connections were made to the output coaxial line. A schematic of the voltage divider and bypass capacitor connections is shown in Fig. 2. It will be noted that the output coaxial line is terminated at the multiplier and not at its output. This helped to reduce the output RC time constant, while absorbing the reflection returning from the unterminated end. The loss of a factor of two in voltage by terminating at the multiplier is compensated by voltage doubling at

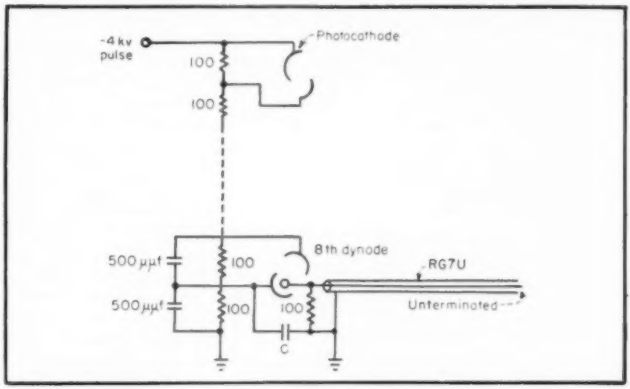

FIG. 2. Voltage divider and by-pass capacitor connections of photomultiplier to output coaxial line

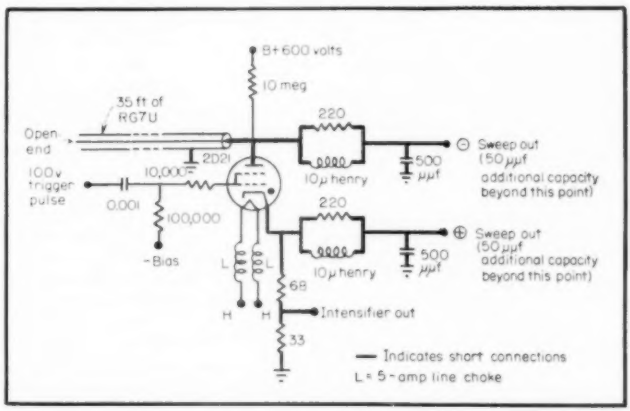

FIG. 3. Fast sweep circuit for oscilloscope

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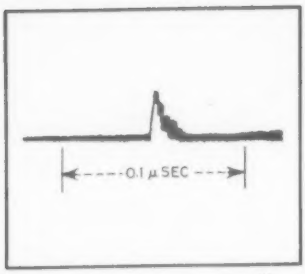

FIG. 4. Pulse obtained with stilbene scintillator

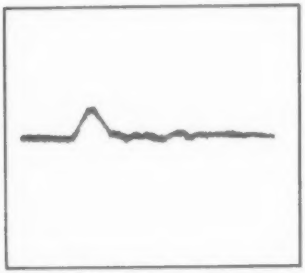

FIG. 5. Pulse obtained with terphenyl in toluene, a liquid scintillator

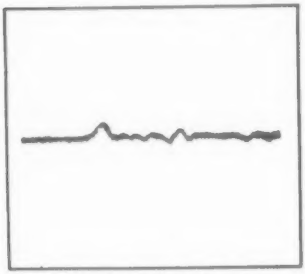

FIG. 6. Single-electron noise pulse

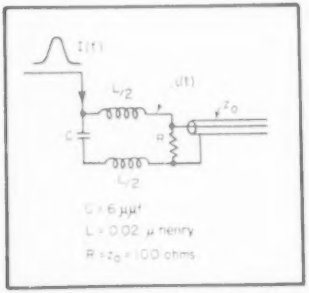

FIG. 7. Equivalent circuit for photomultiplier lead structure

the unterminated end. The special bypass capacitor C was made by returning one lead wire of a tubular 100 $\mu\mu$f ceramic bypass capacitor down through the center of the capacitor, thus bringing out the two leads side-by-side. Inductive effects are thus cancelled out in the capacitor, which now appears merely as a small length of coaxial transmission line, shorted at one end.

Method of Observation

It has already been noted that the multiplier amplifications obtained were about 10^9. At this high a multiplication a single electron leaving the photocathode will produce an output pulse approximately 10 to 15 volts high across a 100-ohm load. It was therefore possible to use oscillographic presentation for all the measurements, without the use of additional amplification. Since the fastest distributed amplifiers which are at present available have a limiting rise time which is considerably longer than those rise times being measured, it can be seen that the use of an amplifier would largely obscure measurements on the speed of the photomultiplier.

In early measurements, a DuMont 5RP11 oscilloscope tube was used. However, because of difficulties arising from transit-time and lead-inductance effects in this tube, the later, and more reliable, data were obtained using a special DuMont tube, the K1032P11. This tube has coaxial input leads to the deflecting plates, and almost negligible transit-time distortion.

A fast repetitive sweep of about 0.08 μsec duration was used in conjunction with the K1032 for many of the experiments. The circuit is shown in Fig. 3. It is a modified version of the sweep circuit described by Soller *et al.* (*2*). The circuit provides a push-pull intensified sweep of about 500 volts amplitude, thus covering the usable portion of the oscilloscope screen. It was triggered in synchronism with the multiplier pulser. Photographs of counts and noise pulses were obtained merely by taking a sufficient number of pictures to insure that some events were caught.

General Results

One of the first results of the measurements was the demonstration of the high speed of response of multipliers of the 931A (and 1P21) type. It was observed that count pulse rise times (10 to 90%) were generally less than 10^{-9} second. Although operation at higher-than-normal voltages can be expected to decrease time-dispersion effects in the multiplier, the decrease should be roughly proportional to the square-root of the voltage increase, so that it would appear that even at ordinary operating voltages these multipliers are faster than had been thought. The experimental results obtained were roughly consistent with the calculations of Sard on time-dispersion effects (*3*), although his computation was intended only as an estimate.

An example of a large count from a stilbene scintillator, as displayed by a 5RP11 oscilloscope tube, is shown in Fig. 4. The measured rise time is slightly more than 10^{-9} second. Part of the initial slope is due to transit-time and input-lead effects in the oscilloscope. The height of the pulse shown is approximately 70 volts, corresponding to a peak output current of 0.7 amp. There is evidently no appreciable saturation present.

This surprisingly high output current capability can be explained by noting that, although the onset of space-charge limiting in a 931A operated at 1 kv total voltage is about 50 ma, limiting occurs not at the ninth dynode, but at the eighth dynode (*4*). Thus, to compute the limit at a higher operating voltage, one needs to include the effect of increased stage multiplication as well as the usual $3/2$-power dependence on the operating voltage. Thus one finds

$$I_{4\text{ kv}} = \left(\frac{4\text{ kv}}{1\text{ kv}}\right)^{3/2}\left(\frac{10}{4}\right) I_{1\text{ kv}} \approx 1.0\text{ amp}$$

A photograph of a scintillation count from a liquid scintillator (terphenyl in toluene) is shown in Fig. 5. The small delayed pulse that is evident is purposely introduced to provide a sweep-speed calibration. It consists of the reflected pulse seen after two traversals of 45 in. of RG7U cable, and corresponds to a time delay of slightly less than 10^{-8} sec. It can be seen that the fluorescence decay time (to $1/e$) is much less than 10^{-8} second, and that the pulse rise time is less than 10^{-9} second. This furnishes information not only on the decay time of the scintillator and the speed of response of the multiplier, but also shows that the statistical excitation chain in this

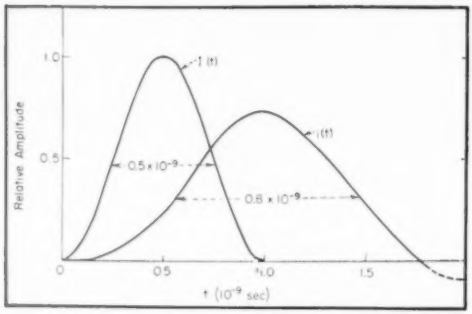

FIG. 8. Pulse broadening by photomultiplier output leads

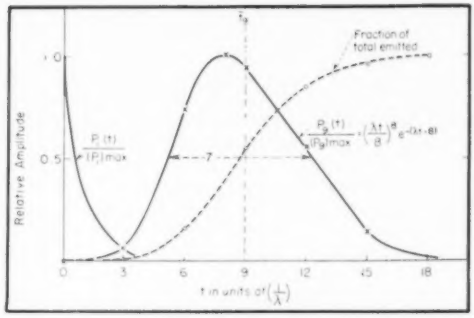

FIG. 9. Differential probability for emission of secondary electrons

liquid scintillator does not give rise to a detectable time dispersion in the initial emission rate of the light.

As noted previously, it was found that the scintillation pulse rise times were about 10^{-9} second or less. This time is considerably shorter than the decay times of the organic scintillators discovered to date. Furthermore, since the noise-pulse experiments, described later, showed that the multiplier-circuit integrating time constants could also be made reasonably short compared to the decay times, it was concluded that the pulsed multiplier as used was sufficiently fast to yield pulse heights proportional to the *rate* of emission of photons from a scintillator. Thus, by photographing scintillation pulses, it was possible to measure the decay times directly. This was done for stilbene, anthracene, and terphenyl in toluene, and has been reported (*5, 6*). In addition, since the system operated as a rate-measuring device, relative pulse-height measurements could then be used to compare the initial rate of emission of photons from various scintillators, per unit excitation energy. The initial rate of photon emission is more important than the total number, for fast counting applications. This comparison was made for stilbene and terphenyl in toluene, when it was found that even though the liquid scintillator emits fewer photons per unit excitation than stilbene, still its initial rate of emission is equal to or perhaps slightly greater than stilbene (*6*).

Noise Counts

It was found that it was just possible to photograph single-electron noise counts from some of the tubes tried. An analysis of such counts is important since it can be used to estimate time-dispersion effects within the multiplier. Although the noise pulse measurements were strictly a by-product of the main problem of developing a fast counting system, it seems worth-while to report them here. This is especially the case in view of the fact that these measurements appear to be at variance with the results found by Law (*7*) in measuring the frequency response of some power multiplier tubes. Law has apparently found evidence for a random delay of secondary electrons, characterized by an exponential delay probability with a time constant of 3×10^{-10} sec. Such a delay could imply a serious limitation on the speed of response of a multistage photomultiplier, such that there would be little hope of being able to develop faster multipliers than those which now exist. The data here reported have not been re-examined in the light of their present significance. It is hoped that reporting them here will stimulate a recheck of our results by some other group.

In the course of the experiments, several single-electron noise counts were photographed. A typical example is shown in Fig. 6. Although the pulses were small, it was possible to measure their width at half-maximum approximately, as presented by the oscilloscope. This turned out to be about 10^{-9} second.

One might hope to be able to estimate the length of the actual noise pulse delivered at the multiplier anode if corrections could be made for (1) oscilloscope distortion effects; (2) dispersion in the coaxial line between photomultiplier and oscilloscope; and (3) the broadening effect caused by the poor high-frequency response of the multiplier leads. These corrections can be calculated, provided the length of the observed pulse is accurately known. This could not be measured with precision, but a value of 1.0 to 1.2×10^{-9} second was taken, as a basis from which to compute the various broadening effects. The estimated corrections (except for the effect of the multiplier leads) are:

1. Transit-time broadening in oscilloscope (beam transit time through plates ≈ 3×10^{-10} sec)	0.5–1.0×10^{-10} sec
2. RC broadening due to oscilloscope plate and coaxial connection capacity	1.0×10^{-10} sec
3. Dispersion effects in coaxial line (45 in. RG7U)	1.0×10^{-10} sec
Total	2.5–3.0×10^{-10} sec

Thus, upon making the indicated corrections, it may be estimated that the length between half-maxima of the noise pulse delivered at the outside of the multiplier was approximately 8×10^{-10} second.

The computation of the correction due to the multiplier lead structure is somewhat more involved. However, it is known that the anode current pulse must be nearly gaussian in shape. It was assumed that the output leads could be represented accurately enough by the lumped anode-to-ninth-dynode capacitance connected through a simple two-wire transmission line to the output coaxial cable and terminating

resistor. Except for the neglect of mutual coupling to other nearby dynode leads in the tube, this equivalent circuit should accurately represent the active circuit. It is estimated that effects due to mutual coupling to other leads should be small, since transmission should occur primarily through the direct wire leads. Because of its short length, about $1\frac{1}{2}$ in., the two-wire line can be represented by two lumped inductances, yielding the equivalent circuit shown in Fig. 7.

The problem is now solved in reverse. That is to say, by successive trial computations the length of a quasi-gaussian current pulse appearing at C is found, which, when broadened by the leads, yields a pulse 8×10^{-10} sec long. The analytic problem was solved by considering the transformation of a unit pulse of the form $\frac{1}{2}(1 - \cos \lambda t)$, which closely approximates a gaussian pulse. The form of the original pulse and its shape after broadening is shown in Fig. 8.

The computed duration of the anode current pulse is seen to be about 5×10^{-10} second. This datum may be used to estimate an upper limit on the delay time in secondary emission by the following considerations: If an exponential delay probability is assumed, with a time constant $1/\lambda$, neglecting for the moment all transit time dispersion effects, then such a delay probability at each stage of a nine-stage multiplier would cause a single-electron pulse at the photocathode to be broadened to a pulse with a shape similar to that shown in Fig. 9. It can be seen from the figure that the delay time constant should be approximately $\frac{1}{7}$ of the width of the broadened pulse. Thus, from the previous noise-pulse data, one would estimate that the delay time must be less than about $(\frac{1}{7}) \times 5 \times 10^{-10}$ sec $\approx 7 \times 10^{-11}$ sec. The presence of appreciable transit-time dispersion effects, highly likely, would still further depress this limit. The figure of 5×10^{-10} sec for the noise-pulse duration may not be accurate, however, because of possible cumulative errors in the corrections applied.

Fast Coincidence System

The original purpose of the investigation was the development of a fast counting system. The experiments described here amply demonstrated the inherent speed of the photomultiplier. It remained only to devise a coincidence circuit of comparable resolving time. This was accomplished by adapting some techniques originated by others (*8, 9*). The K1032P11 oscilloscope tube is used as a coincidence device in the following way: Clipped pulses from each of two pulsed scintillation counters are fed to the horizontal and vertical deflecting plates, respectively. The oscilloscope screen is masked, except for a square opening at one of the quadrants. Single counts in either channel cannot appear from behind the mask, however large their amplitude. Coincident counts of sufficient amplitude can appear, however, and are sensed by a 5819 photomultiplier viewing the screen. Halation from the intensified dot, normally behind the mask, is discriminated against by using a 10^{-8}-sec clipper on the 5819 output lead. Because of the excellent response characteristics of the K1032, the inherent resolving time of the coincidence circuit should be about 2 to 3×10^{-10} sec. An additional advantage of this type of coincidence circuit is its exceedingly short deadtime.

An experimentally determined resolving-time curve for coincident scintillation pulses from two separate pulsed counters is shown in Fig. 10. The displacement of the peak of the curve from the zero delay position is almost entirely accounted for by the delay introduced by beam transit time between horizontal and vertical plates of the oscilloscope. The resolving time of about 7×10^{-10} sec obtained was somewhat poorer than had been expected from the inherent speed of the multipliers and coincidence circuit. It was then recognized that an appreciable broadening of the resolution was arising from statistical effects in the scintillator (*10*), owing to the finite number of photons emitted at each count.

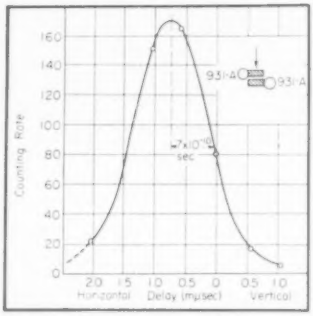

FIG. 10. Coincidence resolution curve for pulses from two separate pulsed counters

The resolution of the system was sufficiently good to enable the detection of the time of flight of fast electrons over a distance of a few centimeters. Because of its resolution, the counting system discriminated excellently against noise counts from the photomultiplier, the chance coincidence from noise counts being lower than one count in several hours, even when set to detect fairly small scintillation counts.

* * *

This article was presented at the Scintillation Counter Symposium, Washington, D. C., January 30, 1952. This work was supported by a contract with the Office of Naval Research.

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ADDENDA

Two additions to the report "Latest Developments in Scintillation Counting" which appeared in the March, 1952, issue, have been received. In the discussion by F. H. Wells, p. 37, the work done by G. Harding on plastic phosphors stemmed from the investigations of M. Pichat of the French Commissariat a l'Energie Atomique. On p. 41, the laboratory counter discussed by R. Y. Parry will, with 1,000 volts on the photomultiplier, give a background count of $1\frac{1}{2}$ cps, and 3×10^{-10} curies of Co^{60} will double this.

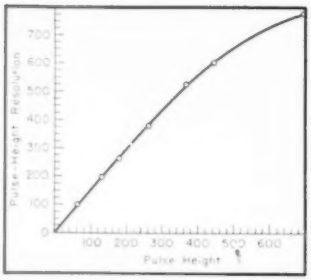

FIG. 1. Pulse-height resolution for alpha-particle scintillations from NaI(Tl). Pulse height is varied by varying the crystal-to-photomultiplier distance

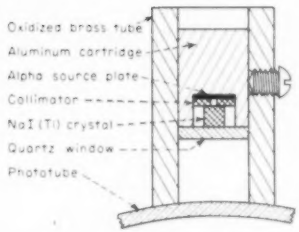

FIG. 2. Scintillation pulse source assembly

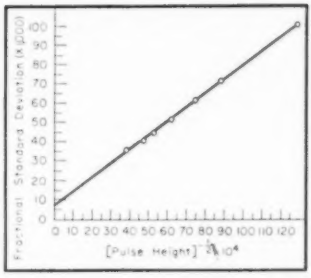

FIG. 3. Pulse-height resolution for alpha-particle scintillations from NaI(Tl). Extrapolation to determine the limiting value of the resolution

Observations on

Pulse-Height Resolution and Photosensitivity

An experimental figure of merit based on statistical theory has been found for 5819 photomultipliers. Nonstatistical fluctuations were minimized and a correction for pulse shaping was applied to the results

By ROBERT K. SWANK and WARREN L. BUCK
Instrument Research and Development, Argonne National Laboratory
Chicago, Illinois

CATHODE EFFICIENCY and the multiplication factor of a photomultiplier tube are statistical quantities; they do not repeat precisely with successive trials. The statistical fluctuations in these quantities are of utmost importance in the measurement of scintillation pulse heights. In particular, if there is a series of identical scintillation events occurring in a crystal, and if the optical geometry is the same for all events, one would expect, were it not for these statistical fluctuations, to observe a series of identical pulses from the multiplier. One observes, however, considerable variations in pulse amplitude, even when great care is exercised to make the individual exciting events as identical as possible.

The theory of these statistical fluctuations has been discussed by several authors (*1, 2*). It is generally assumed that the number of cathode electrons emitted per pulse follows the Poisson law. However, earlier measurements (*3*) indicate that the secondary multiplication process does not follow this law, having indeed a larger fluctuation than that given by the Poisson formula.

The pulse-height resolution of a photomultiplier is here defined as the reciprocal of the fractional mean square deviation of the output pulse amplitudes resulting from a series of identical scintillations. When the effects of the cathode and n dynodes are summed, one obtains an approximation for the resolution, when $m^n \gg 1$

$$R \equiv \frac{(\bar{q})^2}{\overline{q^2} - (\bar{q})^2} = N_e \left[\frac{f}{1 + \epsilon/(m-1)} \right] \equiv N_e F \quad (1)$$

where q = pulse amplitude, N_e = average number of cathode electrons

per pulse, f = fraction of cathode electrons that strikes the first dynode, m = average multiplication per stage, assumed to be the same for all stages, and ϵ = ratio to m of the fractional mean square deviation in m.

The quantity F, as defined above, is a figure of merit for the multiplier, indicating how well the resolution of the cathode pulse is preserved after amplification by the multiplier. One of the purposes of this investigation is to compute F by measuring R and N_e. The corresponding figure of merit for the photocathode is, of course, N_e, the number of emitted photoelectrons for a given incident scintillation. One would expect, in general, that N_e would vary more among different photomultiplier tubes than would F. The factor f should depend on geometrical construction and on cathode-to-first-dynode voltage, while m can be adjusted by varying interdynode voltages. It is not known what factors may influence ϵ.

Since it is frequently desirable to operate the first dynode at a higher accelerating potential than the remaining dynodes, it is useful to generalize Eq. 1 to cover the case where m_1 and ϵ_1 for the first dynode may be different from m and ϵ for the remaining dynodes. Under these conditions

$$R = N_e F = \frac{N_e f}{1 + \frac{\epsilon_1}{m_1} + \frac{\epsilon}{m_1(m-1)}} \quad (2)$$

For an ideal multiplier ($F = 1$), the pulse-height resolution R, as defined by Eqs. 1 and 2 would be numerically equal to the number of cathode electrons N_e in the pulse. In any event one would expect R to be proportional to N_e. This means R is proportional to photocathode efficiency for a given scintillation, or to scintillation magnitude for a given photocathode efficiency.

Scintillation Pulse Source

For Eqs. 1 and 2 to describe the pulse-height resolution of a scintillation counter adequately, it is necessary that nonstatistical factors influencing pulse-height resolution be eliminated, or that a suitable correction be made. In the interest of accuracy in testing these equations, it is desirable that such corrections be made as small as possible. For this purpose, a scintillation source was constructed as shown in Fig. 2. The radiation is monoenergetic alpha particles from a Pu^{239} source. These are slightly collimated and restricted to an area of incidence of $\frac{1}{32}$-in. diameter upon a cleaved NaI(Tl) crystal. The crystal is a $\frac{1}{8}$-in. cube. The crystal and source are sealed together inside an aluminum cartridge with a sealed-on quartz window.

This assembly may be slid back and forth inside a larger ($\frac{7}{16}$-in. inside diameter) oxidized brass tube. The larger tube is mounted on the window of a type 5819 photomultiplier as indicated in Fig. 2. In this way, the scintillation amplitude can be varied over a range of about 16 to 1. The exposed area of the cathode is restricted to the $\frac{7}{16}$-in. diameter circle defined by the oxidized brass tube. Because of the restricted source size and cathode area, distortion of the pulse-height distribution resulting from cathode nonuniformity and unequal optical geometries is minimized.

Pulse-height distributions from this source were observed, using a linear pulse amplifier and ten-channel pulse-height analyzer. With the optical geometry adjusted to a maximum value, the pulse-height distribution approximates a Gaussian distribution with a full width at half maximum of about 5%. As the pulse size is reduced by reducing the optical geometry, this curve retains its general shape, but broadens until the width at half maximum is about 15% for the smallest pulse size. Because of the Gaussian shape, the mean-square deviations were computed from the measured value of the full width at half maximum, using the relations for a Gaussian distribution.

The pulse-height resolution as defined by Eq. 1 has been measured for several pulse heights, using this scintillation source. The results are plotted in Fig. 1. It will be noticed that for small pulse heights, the relationship between pulse-height resolution and pulse height is linear, as predicted by Eqs. 1 and 2. At larger pulse heights, the curve bends over, and would presumably level off to a saturation value. This limiting value of pulse-height resolution should represent the intrinsic resolution due to the alpha source, and to various optical assymmetries which are not of a statistical nature. From the plot in Fig. 1, it is difficult to estimate the value of this limiting resolution. However, if the data is replotted as in Fig. 3, with the fractional standard deviation plotted against the reciprocal square root of pulse height, one obtains a straight-line relationship. This plot, like that of Fig. 2, should be a straight line passing through the origin if Eqs. 1 and 2 are valid. However, in Fig. 3, the effect of "source width" is to displace the line vertically rather than to distort its shape. From this curve, one obtains an extrapolated source width of 0.007; i.e., the plot of Fig. 3 can be made to pass through the origin by subtracting 0.007 from the fractional standard deviation of each point. Similarly, this correction converts the curved plot of Fig. 1 into a straight line passing through the origin. The extrapolated source width corresponds to a limiting value of 20,400 for the resolution of the source.

Cathode Emission

To determine the quantity N_e in Eqs. 1 and 2, it is necessary to make a direct determination of the amount of charge leaving the photocathode during a pulse. It was not practical to measure the cathode pulse heights directly because of the extremely small amplitudes involved. Also, the average electric current from the previously mentioned pulse scintillation source could not be measured, due to the presence of extremely large background currents from the tube. These are of the order of 10^{-11} amperes, a value considerably larger than the dark currents from the photocathode.

To measure the cathode current, a larger NaI(Tl) crystal was employed; this was excited by a gamma-ray source. The same $\frac{7}{16}$-in. diameter cathode area was illuminated as before. By measuring the cathode current with a vibrating-reed electrometer, relative cathode emission values were obtained for 14 type-5819 photomultiplier tubes.

To convert these relative values of cathode emission into absolute measurements of N_e, the following procedure was employed. The cathode and anode currents of one tube were measured with steady light excitation and the multiplier operated at 50 volts per stage. This gave the d-c gain of the multiplier under these conditions. With the same voltage conditions, but using the scintillation pulse source shown in Fig. 2, the anode pulse magnitude was determined. Correc-

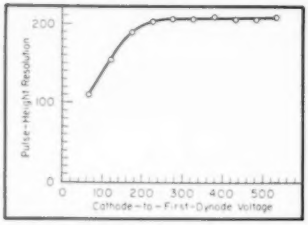

FIG. 4. Effect of first-dynode voltage on pulse-height resolution

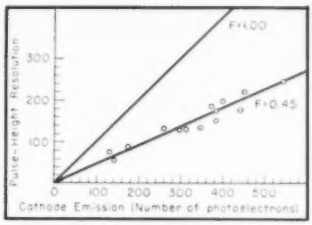

FIG. 5. Absolute pulse-height resolution for 14 photomultipliers

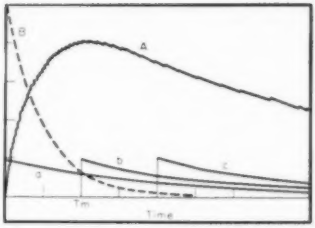

FIG. 6. Diagram of scintillation pulse, discussed in text

tions were made for pulse shaping, so that the total average anode charge per pulse could be determined. These corrections were based on the assumption of an exponential form for the scintillation decay. The average anode charge per scintillation divided by the d-c gain of the multiplier gave N_c.

Pulse-Height Resolution

The same 14 photomultiplier tubes for which the cathode emission measurements were made were also examined for pulse-height resolution. The scintillation pulse source was adjusted so that pulse-height resolution values of the order of 100–200 were obtained. This makes the statistical width large compared to the estimated source width; in other words, measurements were made in the pulse-height range where good linearity was observed in Fig. 1. The source-width correction amounted to only about 10%.

For these measurements, the first dynode was operated at approximately 280 volts accelerating potential. As shown in Fig. 4, this results in nearly optimum resolution conditions, and also minimizes the dependence of resolution on first-dynode voltage. In each case, the total multiplier voltage was adjusted to give a constant output pulse size. In this way the multiplier gain is made proportional to the reciprocal of the cathode emission. However, the gain per stage varied only slightly as a result of this.

Correlation of Results

The results of both cathode emission and pulse-height resolution for the 14 tubes measured are given in Fig. 5. These results show that the pulse-height resolution of a photomultiplier tube is actually proportional to cathode efficiency, as predicted by Eq. 2. The data given here is not adequate to evaluate all the parameters in Eq. 2. The value of m_1 and m can be estimated from the gain of the multiplier, by using the data of Morton (*1*) on multiplication as a function of voltage. Applying this to the average conditions of Fig. 5, one gets $m_1 = 6$, $m = 2.6$. If we use Morton's value of 1.5 for ϵ, we then find $f = 0.64$.

Other Factors

In addition to the correction for source resolution, one other correction which has been made in the data of Fig. 5 should be noted. That is the correction for the loss of statistics introduced as a result of pulse shaping. This effect can be seen from the curves in Fig. 6. Curve A represents the scintillation pulse at the anode. It is assumed that the anode-circuit time constant RC is greater than the phosphor decay time τ. This pulse will reach its peak at time

$$T_m = \frac{RC}{\gamma - 1} \log \gamma \qquad (3)$$

where $\gamma = RC/\tau$. It is seen that curve A is not a continuous smooth curve, but is a pile-up of a great many individual photoelectron pulses. Several of these component pulses are shown in curves a, b, and c. Curve B is the phosphor decay curve. It defines the frequency of occurrence of the individual photoelectron pulses. If our pulse-height analyzer records the peak value of A, then it is clear that pulse c contributes nothing to this measurement, and therefore is a total loss statistically. The fraction of such wasted photoelectrons is

$$w = e^{-\frac{T_m}{\tau}} = \gamma^{-\frac{\gamma}{\gamma-1}} \qquad (4)$$

and the fraction remaining is

$$f' = 1 - w = 1 - \gamma^{-\frac{\gamma}{\gamma-1}} \qquad (5)$$

Furthermore, it is apparent that pulses a and b are weighted unequally in the sum at T_m. The form of this weighting function is

$$P(v)dv = BV^{-(1+\gamma)}dV \qquad (6)$$

and its fractional mean square deviation is

$$\delta = \frac{(1 - \gamma^{-\frac{\gamma}{\gamma-1}})(1 - \gamma^{-\frac{\gamma-2}{\gamma-1}})}{\gamma(\gamma - 2)} - 1 \qquad (7)$$

These effects are taken into account if Eq. 2 is modified to read

$$R' = N_c \frac{ff'}{1 + \frac{\epsilon_1}{m_1} + \frac{\epsilon}{m_1(m-1)} + \delta} \qquad (8)$$

In most cases δ will be a very small effect. For example, if $RC = 4\tau$, $\delta = 0.018$. The data of Fig. 5 has already been corrected for f' and δ.

One factor which has been left unmentioned in the preceding discussion is the effect of ion feedback afterpulses. These have been observed on the oscilloscope by the authors during the course of these measurements. Their effect is to produce a very ragged bump in the pulse, about 1 μsec after the beginning of the pulse. It is believed that these afterpulses fluctuate more in amplitude than the electron pulses. The presence of these effects dictated the use of a rather short anode time constant in these experiments. In this way, the peak occurs at about 0.6 μsec, before very much effect can be produced by ion feedback.

* * *

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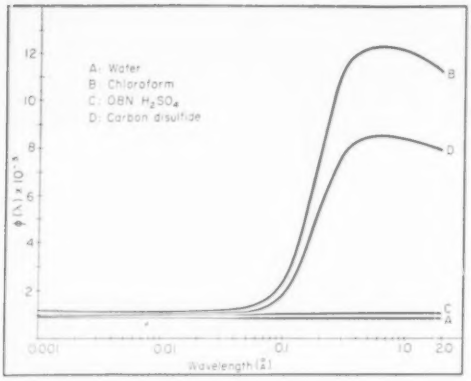

FIG. 9. Wavelength variation of absorption-coefficient ratio

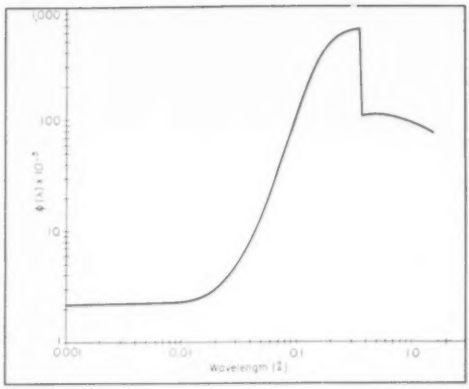

FIG. 10. Variation of absorption-coefficient ratio for CH_2I_2

Energy Absorption by Externally Irradiated Liquids—II*

Calculations necessary for finding the energy absorption by converting from ionization-chamber measurements are given. Applications to chemical dosimetry are also considered

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DETERMINATION OF the energy absorbed when liquids are exposed to high-energy X- or γ-rays was discussed in Part I. To make this determination it is necessary to convert from ion-chamber measurements. The calculations for this conversion are given here.

The first method of calculation for a liquid sample is illustrated by the following equations†

$$\bar{I}(\lambda) = \frac{1}{V}\int_V I_v(\lambda)\, d\lambda \qquad (4)$$

$$E(\lambda) = 0.1083\phi(\lambda)\frac{\bar{I}(\lambda)}{I_0(\lambda)}\frac{f(\lambda)\, d\lambda}{\int_\lambda f(\lambda)\, d\lambda} \qquad (5)$$

$$E = \int_\lambda E(\lambda)\, d\lambda \qquad (6)$$

Equation 4 will give the average intensity throughout the irradiated volume for the wavelength range λ to $\lambda + d\lambda$. Multiplication of $\bar{I}(\lambda)/I_0(\lambda)$ by the fraction of the incident energy in the range $d\lambda$, by the absorption-coefficient ratio $\phi(\lambda)$, and by the constant 0.1083, as in Eq. 5, gives the average energy absorption for the range λ to $\lambda + d\lambda$. Summation of this result, as in Eq. 6, yields the average absorption over the whole range of wavelengths. The limits of integration on λ are from λ_0 to ∞ (or to as large a wavelength as gives any contribution to the energy), and the

* Part I of this two-part article appeared in NUCLEONICS, April '52, page 47.

† Equations 1–3, Figs. 1–8, and Table 1 appeared in Part I.

volume integration covers the whole sample. In Eq. 5, each of the terms on the right, except the constant factor, is dimensionless.

It is evident from Eq. 5 that $E(\lambda)$ is dependent both on the type of source and on the nature of the sample. $\bar{I}(\lambda)$ is similarly dependent, while $f(\lambda)$ is related to the source alone, and $\phi(\lambda)$ is a property of the substance being irradiated. An interesting case arises if $\phi(\lambda)$ is invariant with wavelength, since then the energy absorption (and consequently the amount of chemical change for a constant dose*) does not depend on λ if the sample is sufficiently small. Since the constancy of $\phi(\lambda)$ represents a rather special condition, let us examine in somewhat more detail when it might be expected to be found.

Each component of the total linear absorption coefficient is dependent on both λ and Z. This is shown for the scattering coefficients σ_a and σ_s by the equations

$$\sigma_a = d[{}_a\sigma_a(1/A)N_0Z] \qquad (6a)$$
$$\sigma_s = d[{}_a\sigma_s(1/A)N_0Z] \qquad (6b)$$

The wavelength dependence enters through the Klein-Nishina electron coefficients, as shown in Table 2, whereas the atomic-number dependence arises from variation in the percentage of protons in the nucleus. However, the atomic-number dependence for these coefficients is small compared to the variation found for the photoelectric coefficient, τ, since $0.40 < Z/A \leq 0.50$. A number of single-term expressions of the form $\tau = C\,Z^m\,\lambda^n$, where m is of the order of 4, have been given for this coefficient, but the following two-term equation due to Victoreen (*21*) gives a better fit with the experimental data

$$\tau = d[\alpha Z^4\lambda^3(2Z/A) - \beta Z^5\lambda^4(2Z/A)] \qquad (7)$$

where α and β are polynomials in Z.

Equations 6a, 6b, and 7 are for the coefficients of elementary substances, but corresponding values for compounds or mixtures are readily derived from the equation of Walter (*48*)

$$\tau/d = \sum_i p_i\,(\tau/d)_i \qquad (8)$$

Here τ/d is the mass photoelectric coefficient for the mixture, p_i is the fraction by weight of the substance i in the mixture, and the $(\tau/d)_i$ are the mass photoelectric coefficients for the individual elements in the mixture. The other coefficients for compounds can be calculated from a similar type of linear combination formula.

Similarly, when the photoelectric absorption of compounds or mixtures is under consideration, an atomic number should be used which is representative or "effective" for the compound as a whole. This is derived by combination of the atomic numbers of the elements according to some formula such as

$$\bar{Z} = [\Sigma\, a_i Z_i^{2.94}]^{1/2.94} \qquad (9)$$

where a_i is the fractional electron content of the element Z_i in the compound. The mathematical form of this expression will vary somewhat, depending on the formula used for the photoelectric coefficients of the elements, but the numerical values should not vary much. Equation 9 was derived from a formula given by Walter (*48*).

Calculated values of the absorption coefficients, α_1 and α_2, for a number of materials are given in Table 3.

Returning now to consideration of $\phi(\lambda)$, it becomes clear that this function can be a constant if, and only if, the absorption coefficients of the medium and of air vary with wavelength in such a way that their ratio does not change. This is nearly equivalent to the somewhat less precise statement that the effective atomic number of the sample is the same as that for air.

Figures 9 and 10 show the variation of $\phi(\lambda)$ with λ for water, 0.8*N* H_2SO_4, carbon disulfide, chloroform, and methylene iodide. These liquids were chosen for the following reasons:

1. Dilute aqueous solutions, which are being rather widely studied in radiation chemistry experiments, are nearly identical with water in respect to energy absorption.

2. 0.8*N* sulfuric acid is used as the solvent in the ferrous sulfate dosimeter (*45*).

3. Carbon disulfide has been suggested for use in liquid ionization chambers (*50*).

4. A colorimetric dosimeter for γ-rays, based on the formation of acid in irradiated chloroform, has been proposed recently (*43*).

5. Methylene iodide is of interest since it illustrates the behavior to be

Symbols Used

- τ = linear photoelectric absorption coefficient
- σ_a = linear true absorption coefficient
- σ_s = linear scattering absorption coefficient
- α = generalized absorption coefficient
- $\alpha_1 = \mu = \tau + \sigma_a + \sigma_s$
- $\alpha_2 = \tau + \sigma_s$
- $\alpha_{2L} = \tau + \sigma_s$ for the liquid
- $\alpha_{2A} = \tau + \sigma_s$ for air
- λ = wavelength
- λ_0 = cutoff wavelength
- V = volume
- A = area
- I = intensity
- I_0 = incident intensity (total)
- $\bar{I}(\lambda)$ = average intensity for the range λ to $\lambda + d\lambda$
- I_v = local intensity for the volume element dV
- I_A = local intensity for the area element dA
- $I(x)$ = intensity at distance x from a reference point in a coordinate system
- $E(\lambda)$ = average energy absorption per unit volume for λ to $\lambda + d\lambda$
- E = average energy absorption per unit volume (total)
- $f(\lambda)d\lambda$ = incident energy for the range λ to $\lambda + d\lambda$
- $\phi(\lambda) = \alpha_{2L}/\alpha_{2A}$
- J = number of ion pairs formed per unit volume in air
- W = energy required to form one ion pair
- ρ = ratio of the energy absorbed from electrons per unit path length in the medium to the same quantity in air
- d = density
- f = distance from the focal spot of X-ray tube to the coordinate origin
- R = radius
- ${}_a\sigma_a$ = Klein-Nishina absorption coefficient
- ${}_a\sigma_s$ = Klein-Nishina scattering coefficient
- N_0 = Avogadro's number
- n = number of electrons/cm^3
- Z = atomic number
- $\bar{Z}$ = effective atomic number

* This will be true only if there are no effects caused by a change in specific ionization.

expected in crossing an absorption discontinuity.

The solution of Eqs. 4, 5, and 6 can be illustrated by the elementary case of a cylindrical cell of radius R and height h (Fig. 11), filled with fluid and closed at top and bottom with 1-mm Pyrex disks. The radiation field is parallel and of uniform intensity, I_0, over the top face. The decrease in intensity due to spreading of the beam is neglected since it is assumed that the ratio h/f is small. Under these conditions, Eq. 4 is transformed as follows

$$V = \pi R^2 h;\ dV = \pi R^2 dx$$
$$I_v(\lambda) = I_0(\lambda) e^{-\alpha_1 x}$$

$$\bar{I}(\lambda) = \frac{1}{V}\int_V I_v(\lambda) dV$$

$$= \frac{1}{\pi R^2 h}\int_0^h I_0(\lambda) e^{-\alpha_1 x}\pi R^2\, dx$$

$$\frac{\bar{I}(\lambda)}{I_0(\lambda)} = \frac{1}{\alpha_1 h}[1 - e^{-\alpha_1 h}] \qquad (10)$$

A plot of Eq. 10 against the cell thickness is given in Fig. 12 for water and for several wavelengths.

If h/f is not small, evaluation of $\bar{I}(\lambda)$ requires integration of Eq. 11, which results from assuming that the radiation field follows the inverse square law,

$$\bar{I}(\lambda) = \frac{I_0(\lambda) f^2}{h}\int_0^h \frac{e^{-\alpha_1 x}}{(f+x)^2}\, dx \qquad (11)$$

This leads to an expression which is somewhat complicated for computational purposes. A simpler but less rigorous procedure consists in averaging separately for the effect of absorption and inverse-square variation, and combination of the results. If this is done, it turns out that Eq. 10 will be multiplied by the correction factor $f/(f+h)$.

Since $\phi(\lambda)$ will not in general be expressible in a simple form, it appears preferable to replace the integral in Eq. 6 by a summation. This is done in Table 4 for $h = 3$ cm, using the data from Greenfield *et al.* (*30*) for the energy distribution in 250-kv X-radiation filtered by 0.2 mm copper and 1.0 mm aluminum. The data are shown in Fig. 4.

Summation of the figures in the last column of Table 4, and multiplication by 0.1083 gives the value 75.0 as the average energy absorption, E, in ergs per cubic centimeter per roentgen for water, under the conditions described. This is converted to ion-pairs by multiplication by 1.921×10^{10}. Corrections for the decrease in intensity due to absorption by the glass wall are given in Table 5. The wall correction amounts to only about 3.5% in this case, which might be considered negligible in comparison with other errors. However, it will be appreciably greater for lower-energy radiation.

TABLE 2—Klein-Nishina Absorption Coefficients per Electron

Wavelength (Å)	$_e\sigma_a$ ($\times 10^{25}$)	$_e\sigma_s$ ($\times 10^{25}$)
2.0	0.0767	6.4173
1.8	0.0842	6.3926
1.6	0.0948	6.3617
1.4	0.1078	6.3224
1.2	0.1238	6.2712
1.0	0.1462	6.2007
0.8	0.1786	6.1000
0.6	0.2290	5.9349
0.5	0.2666	5.8108
0.4	0.3189	5.6349
0.3	0.3963	5.3657
0.2	0.5213	4.9032
0.15	0.6166	4.5202
0.125	0.6771	4.2583
0.10	0.7526	3.9221
0.09	0.7805	3.7614
0.08	0.8143	3.5790
0.07	0.8498	3.3720
0.06	0.8864	3.1345
0.05	0.9231	2.8590
0.04	0.9570	2.5343
0.03	0.9820	2.1431
0.02	0.9812	1.6551
0.01	0.8899	1.0057
0.008	0.8409	0.8446
0.006	0.7984	0.6739
0.004	0.6550	0.4727
0.002	0.4630	0.2529
0.001	0.3037	0.1314

The same method of calculation can be used for other cells of simple geometry, but a somewhat different method will be used for a spherical cell where it is more difficult to formulate I_v in terms of the coordinates of the sphere. For this case, the average intensity is required over planes tangent to the sphere at opposite poles, and the energy absorption in the fluid is estimated by difference. For a part of the interplanar distance, the radiation passes through air, but the decrease in intensity due to absorption by air is neglected in comparison to absorption by the liquid. In Fig. 11 the intensity is uniformly I_0 over the top tangent plane, and over the bottom plane it is averaged within the boundaries shown; r and θ are polar coordinates in the bottom plane.

The average over the bottom plane is carried out as follows

$$\bar{I}(\lambda) = \frac{1}{A}\int_A I_A(\lambda)\, dA$$

$$= \frac{1}{A}\int_0^R\int_0^{2\pi} I_0(\lambda) e^{-\alpha_1 d} r\, dr\, d\theta$$

$$= \frac{2\pi I_0(\lambda)}{A}\int_0^R e^{-\alpha_1 d} r\, dr$$

$$= \frac{2\pi I_0(\lambda)}{A}\int_0^R e^{-2\alpha_1\sqrt{R^2-r^2}} r\, dr$$

since $d = 2\sqrt{R^2 - r^2}$.

Let $z^2 = R^2 - r^2$, then $2zdz = -2rdr$, and $rdr = -zdz$; $z = R$ when $r = 0$, and $z = 0$ when $r = R$. Then, after simplification, the equation becomes

$$\bar{I}(\lambda) = \frac{2I_0(\lambda)}{R^2}\int_0^R e^{-2\alpha_1 z} z\, dz$$

$$= \frac{I_0(\lambda)}{2\alpha_1^2 R^2}[1 - e^{-2\alpha_1 R}(1 + 2\alpha_1 R)] \qquad (12)$$

Then
$$E(\lambda) = \frac{A}{V}[I_0(\lambda) - \bar{I}(\lambda)]$$
$$= \frac{3}{4R}[I_0(\lambda) - \bar{I}(\lambda)]$$

and
$$E = \int_\lambda E(\lambda) d\lambda$$

Equation 12 is positive definite since $1 + 2\alpha_1 R$ is always less than $e^{2\alpha_1 R}$. Summation of the energy absorption over the continuous spectrum, and the correction for the glass wall may be carried out as in the previous example. In using Eq. 12, it is necessary to have accurate values for α_1 since the second term in the brackets is often small.

Chemical Dosimetry

It was shown at the beginning of the first article that these calculations can be expected to be accurate only if the sample volume is close to that given as case 2. However, since the limits for this volume cannot be well defined, it is likely that there will be an overlap into the regions given under case 1 or case 3. The uncertainty associated with this step, together with the other computational errors and the inaccuracy to be expected with an ionization-chamber measurement (±10%) may lead to a value for the average energy absorption which departs considerably from the true figure.

An error in the value used for E will, of course, be reflected in the ionic yields found in chemical experiments since the latter are calculated from chemical data under the assumption that 32.5 ev are required for the formation of an

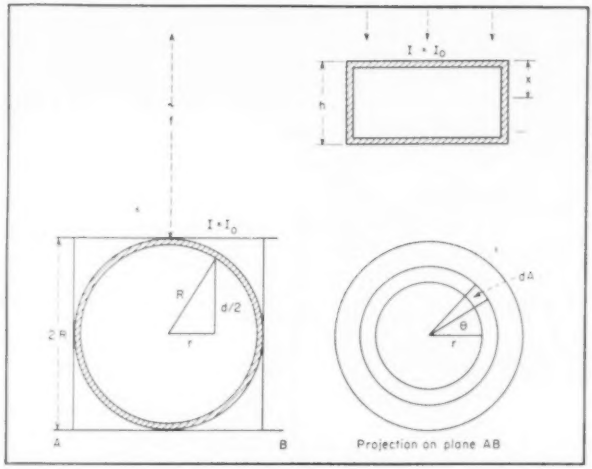

FIG. 11. Geometry of a cylindrical cell, used for solving the equations

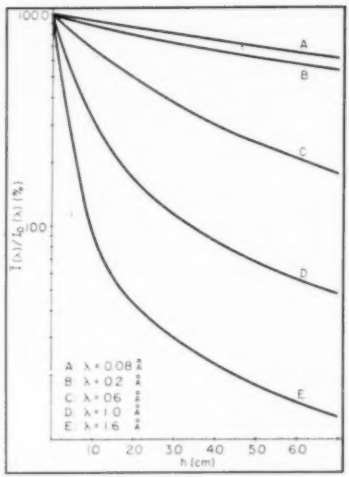

FIG. 12. Ratio of average intensity to incident intensity as a function of cell thickness for water

TABLE 3—Calculated Absorption Coefficients for Various Materials

Wavelength (Å)	Air ($d = 0.001293$)* α_1 ($\times 10^3$)	Air ($d = 0.001293$)* α_2 ($\times 10^3$)	Water ($d = 1$) α_1	Water ($d = 1$) α_2	0.8N H_2SO_4 ($d = 1.05$) α_1	0.8N H_2SO_4 ($d = 1.05$) α_2	CS_2 ($d = 1.2628$) α_1	CS_2 ($d = 1.2628$) α_2	$CHCl_3$ ($d = 1.4983$) α_1	$CHCl_3$ ($d = 1.4983$) α_2	CH_2I_2 ($d = 3.325$)† α_1	CH_2I_2 ($d = 3.325$)† α_2
2.0	268.28	265.78	19.826	19.612	27.241	27.017	209.86	209.62	297.69	297.41		
1.8	197.79	195.31	15.888	15.674	20.078	19.855	156.21	155.97	222.26	221.98		
1.6	140.74	138.27	11.279	11.066	14.279	14.057	112.00	111.76	159.81	159.53	978	978
1.4	95.83	93.37	7.664	7.453	9.714	9.493	76.593	76.353	109.58	109.30	725	725
1.2	61.72	59.28	4.928	4.719	6.246	6.027	49.257	49.019	70.641	70.366	482	482
1.0	37.01	34.60	2.954	2.747	3.734	3.518	29.146	28.911	41.882	41.610	309	309
0.8	20.26	17.89	1.621	1.417	2.031	1.819	15.315	15.083	22.030	21.762	170	170
0.6	9.972	7.664	0.804	0.606	0.986	0.778	6.711	6.486	9.639	9.379	81.8	81.8
0.5	6.763	4.504	0.550	0.356	0.660	0.457	4.013	3.792	5.744	5.489		
0.4	4.576	2.385	0.377	0.189	0.438	0.241	2.180	1.966	3.093	2.846	25.3	25.3
0.3	3.198	1.112	0.268	0.0886	0.298	0.111	1.050	0.847	1.460	1.224	67.796	67.338
0.2	2.394	0.488	0.204	0.0398	0.218	0.0472	0.454	0.268	0.599	0.384	23.336	22.918
0.15	2.118	0.360	0.181	0.0301	0.191	0.0338	0.300	0.129	0.378	0.180	10.706	10.321
0.125	1.936	0.333	0.170	0.0281	0.179	0.0307	0.249	0.0868	0.305	0.119	6.541	6.178
0.10	1.854	0.328	0.159	0.0280	0.167	0.0299	0.209	0.0599	0.251	0.0786	3.624	3.290
0.09	1.792	0.330	0.154	0.0281	0.161	0.0299	0.195	0.0525	0.232	0.0675	2.765	2.444
0.08	1.727	0.335	0.148	0.0286	0.155	0.0303	0.183	0.0470	0.216	0.0591	2.064	1.758
0.07	1.654	0.342	0.142	0.0294	0.149	0.0309	0.171	0.0431	0.201	0.0530	1.504	1.217
0.06	1.572	0.352	0.135	0.0302	0.141	0.0317	0.160	0.0405	0.186	0.0488	1.071	0.804
0.05	1.475	0.363	0.127	0.0312	0.132	0.0327	0.148	0.0390	0.172	0.0462	0.749	0.505
0.04	1.360	0.374	0.117	0.0322	0.122	0.0336	0.135	0.0384	0.156	0.0449	0.518	0.302
0.03	1.216	0.383	0.105	0.0329	0.109	0.0344	0.119	0.0379	0.138	0.0443	0.360	0.177
0.02	1.026	0.382	0.0881	0.0328	0.0913	0.0335	0.100	0.0375	0.116	0.0434	0.253	0.112
0.01	0.737	0.346	0.0634	0.0297	0.0661	0.0310	0.0720	0.0338	0.0832	0.0391	0.165	0.0794
0.008	0.655	0.327	0.0563	0.0281	0.0588	0.0293	0.0640	0.0320	0.0740	0.0369	0.1455	0.0752
0.006	0.573	0.310	0.0492	0.0267	0.0514	0.0279	0.0559	0.0304	0.0646	0.0350	0.1264	0.0689
0.004	0.439	0.255	0.0377	0.0219	0.0393	0.0229	0.0429	0.0249	0.0495	0.0287	0.0964	0.0561
0.002	0.278	0.180	0.0239	0.0155	0.0250	0.0162	0.0272	0.0176	0.0314	0.0203	0.0611	0.0395
0.001	0.169	0.118	0.0145	0.0102	0.0152	0.0106	0.0165	0.0115	0.0191	0.0133	0.0371	0.0259

* These are for dry air of the composition: $O_2 = 23.2\%$, $N_2 = 75.5\%$, and $A = 1.3\%$.

† The Victoreen formula is valid only for wavelengths shorter than the K absorption discontinuity, which for iodine is at $\lambda = 0.373$ Å. The data for longer wavelengths were taken from Compton and Allison (49).

ion pair in a liquid medium. In particular, the figure of 1.6×10^{12} ion pairs/cm³/r, which has been rather widely used, cannot be considered as correct for the general case.*

Chemical dosimetry suggests itself as a useful method to avoid the rather uncertain calculations, particularly for experiments where there may be unfavorable geometry. In this method, the chemical change in a test sample is compared with that for a reference solution which is irradiated under the same conditions, preferably simultaneously. The relation between the energy absorption and the amount of chemical change should be well established for the reference solution, and its effective atomic number should be nearly the same as that for the test solution. With respect to this condition alone, any dilute aqueous solution can be used as a dosimeter for any other dilute aqueous solution.

The requirements for chemical dosimeters will naturally depend considerably on the use to which they are to be put. For use as a monitor for radiation chemistry experiments under laboratory conditions, one would like to have stability, reasonable sensitivity, and simple analysis, together with independence of dosage rate and wavelength. It would be expected that if $\phi(\lambda)$ is constant, the latter condition would be assured. Several dosimeter solutions have been proposed so far, none of which can be considered completely satisfactory (*43–47*).

The reactions of radiation chemistry can be conveniently classified with respect to sensitivity into the three following groups: (1) ionic yield ≤ 1.0, (2) ionic yield of 1–4, and (3) ionic yield of 4–500,000. Most of the reactions fall into groups 1 and 2 since only a few are known with an ionic yield greater than 4.

For monitoring the reactions in groups 1 and 2, and in the lower range of group 3, a dilute, air-saturated sulfuric acid solution of Fe^{++} appears to be the best dosimeter available at present. It fulfills the requirements mentioned above, but its sensitivity is rather low and the relation between the amount of chemical change and the energy absorbed is not known as well as would be desired.

The chloroform dosimeter (*48*) is much more sensitive since it is based on a chain reaction with an ionic yield of around 2,000. It appears at present that this may prove to be a useful instrument for the monitoring of γ-radiation. However, it must be used with some caution in the X-ray region due to the large wavelength variation of $\phi(\lambda)$.

The question arises as to a suitable way of calibrating the dosimeters which will be free from the ambiguities associated with electronic equilibrium and absorption of scattered radiation. A method suggested by Miller approaches the problem in a fundamental way (*45*). In this method, a material is selected for the cell wall for which the value of the stopping power, ρ, is nearly the same as that for the dosimeter solution. Accordingly, electronic equilibrium is established in the wall, and there is no transition layer as the radiation passes from the wall into the liquid in the cell. An identical cell filled with air instead of the liquid is used for the ionization measurements. The energy absorbed in the liquid is obtained from Eq. 3.

Another method would be a measurement of the chemical change in the dosimeter following the addition of a known amount of a pure β-emitting isotope for which the energy spectrum is well known. Here the use of a large sample would be preferable since as the volume gets large the fraction of the beta-ray energy which escapes from the liquid sample will become a negligible quantity.

* * *

The author is indebted to the Institute for Numerical Analysis at the University of California for the calculation of the coefficients in Table 2.

TABLE 4—Summation Values For Finding Average Energy Absorption

Range of λ (Å)	*Per cent of incident energy*	$\phi(\lambda)$	$I(\lambda)$	$E(\lambda)$
0.05–0.1	10	855	1.00	85.5
0.1–0.12	10	848	0.99	84.0
0.12–0.14	10	845	0.98	82.8
0.14–0.16	10	845	0.98	82.8
0.16–0.185	10	825	0.97	80.0
0.185–0.22	10	820	0.96	78.7
0.22–0.275	10	810	0.93	75.3
0.275–0.375	10	795	0.81	64.4
0.375–0.45	5	790	0.64	25.6
0.45–0.55	4	790	0.52	16.4
0.55–0.65	2.5	790	0.39	7.7
0.65–0.75	1.5	790	0.28	3.3
0.75–0.85	1	790	0.21	1.6
0.85–1.0	1	790	0.15	1.2
>1.0	5	790	0.08	3.2

TABLE 5—Corrections For Decrease in Intensity Due to Absorption by Glass Wall

Range of λ (Å)	$E(\lambda)$ *Uncorrected*	$E(\lambda)$ *Corrected*
0.05–0.10	85.5	84.9
0.1–0.12	84.0	83.3
0.12–0.14	82.8	81.9
0.14–0.16	82.8	81.5
0.16–0.185	80.0	78.6
0.185–0.22	78.7	77.8
0.22–0.275	75.3	72.3
0.275–0.375	64.4	58.9
0.375–0.45	25.6	21.7
0.45–0.55	16.4	12.4
0.55–0.65	7.7	4.9
0.65–0.75	3.3	1.7
0.75–0.85	1.6	0.6
0.85–1.0	1.2	0.5
>1.0	3.2	1.6

* This figure is obtained by multiplication of the number of ion pairs per esu per cm³ in air at normal temperature and pressure by the ratio of the densities of water and air.

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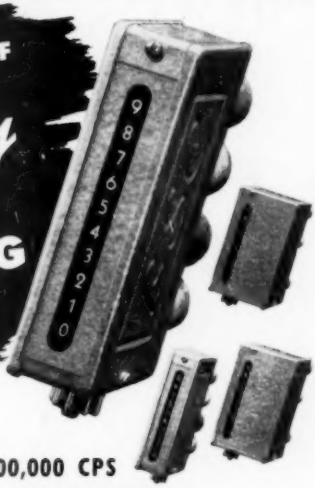

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FIG. 1. Probe counter and mount, counting-rate meter, and indicator and alarm

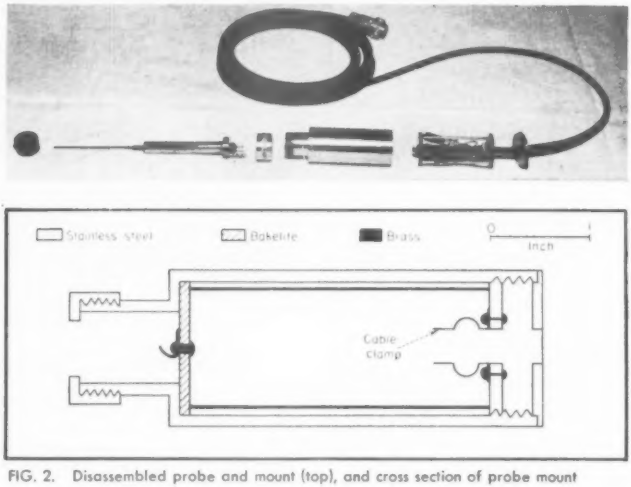

FIG. 2. Disassembled probe and mount (top), and cross section of probe mount

Mount, Electronics, and Indicator for Probe Counter

By THEODORE FIELDS

Radioisotope Unit
Veterans Administration Hospital
Hines, Illinois

Previous reports (*1–3*) have demonstrated the possibility of using P^{32} for localization of brain tumors during surgery. Early studies conducted at this laboratory indicated that the feasibility of this procedure was in doubt because of technical limitations. The life of the needle counter was very short, and the instrumentation was needlessly large.

To overcome these limitations, the equipment shown in Fig. 1 has been developed. A waterproof mount with a built-in preamplifier is mounted directly on the needle probe,* as shown in Fig. 2. A long shielded cable connects the probe unit to a counting-rate meter with indicator and timer.

The mount is shown in Fig. 2. Stainless-steel construction is employed, with a cold-setting cement used for waterproofing. The preamplifier circuit shown in Fig. 3 can be slightly modified, depending upon the attached counting-rate circuit. The complete circuit is mounted on a permanently fixed terminal strip to which the ends of the five-conductor shielded cable are attached. The cable is fastened to the inside of the mount cylinder by a cable clamp, and is gasketed with a cement† that is impervious to cold-sterilization solutions.

The preamplifier employs a subminiature radio tube (CK 5703) in a conventional cathode-follower circuit. A shielded or highly insulated cable should be used to provide maximum high voltage protection (approximately 1,100 volts). As much as 16 ft of cable can be used between the preamplifier and meter in this device. A minimum signal of 0.25 volts from the needle probe actuates the cathode follower.

A counting-rate meter‡ was selected as superior to a scaler in this instance because of ease of operation. After the high voltage has been adjusted, no additional switch operation is necessary for using the probe. For a 3% probable error of the mean, the equilibrium rise time (*4*) is less than 15 sec at the counting rates encountered in normal operation.

The indicator and time alarm are connected to the modified counting-rate meter. For distant viewing, an 8-in. meter is wired in parallel with the counting-rate meter. A synchronous motor with contact fingers rings a bell and switches on a light every 15 sec, at which time a reading may be taken.

Once the needle probe is securely fastened to the preamplifier and permanently gasketed with rubber cement,

* Manufactured by H. W. Leighton, Glen Ridge, N. J.

† Manufactured by E. I. du Pont de Nemours & Co., Inc., Wilmington, Del., (Duco Cement).

‡ Manufactured by Nuclear Instrument and Chemical Corp., Chicago, Ill., and modified by author from model 1615.

the procedure adopted in using the equipment consists of the following:

1. The five-prong cable plug is covered with a rubber finger cot that is held in place with a rubber band.

2. The cable, preamplifier, and probe are immersed in a cold-sterilization solution for one hour. A plastic radioactive button (NICC model R2), in which a one-eighth inch hole is drilled one-quarter inch deep, is simultaneously sterilized. Upon removal from the solution the set with the button is placed in a sterile towel and put on a sterile instrument table.

3. The counting-rate meter and indicator-timer is placed at the foot of the operating table and turned on at least 15 minutes before using.

4. The socket end of the cable is plugged into the counting-rate meter. The needle probe is placed in the radioactive button and the high voltage set at 75 volts above starting potential. Correct operation of the probe is assured by checking the counting rate obtained with the radioactive button.

5. When ready for use, the indicator-alarm is turned on. The surgeon then inserts the needle probe at various locations and various depths for 15-sec periods. The needle is cleansed in sterile saline between insertions and may rest on the instrument table between usages.

6. Caution is recommended to all personnel using the needle probe because of its inherently sensitive construction. Flexing of the needle is to be avoided, and there should be no jarring of the probe.

There has been a minimum of difficulty in recent operations. A surgical attendant has been trained in the simple steps involved in connecting the equipment, and the operation of the probe is continually available to the neurosurgeon after the equipment has been turned on. A report on the surgical results of this device is presently being prepared.

* * *

This article is published with the approval of the Chief Medical Director, Veterans Administration. The statements and conclusions made by the author are the result of his own study and do not necessarily reflect the opinion or policy of the Veterans Administration.

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Berkeley Cyclotron Oil Difficulties

By J. VALE

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University of California
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The difficulty encountered with the magnet coils of the 184-inch cyclotron at Berkeley, California, might be of interest to others that operate oil-cooled machines. The trouble showed up as a progressive heating of the lower coil tank during the past two years. An investigation into the problem indicated that the difficulty must be at the heat exchanger used to cool the oil. Consequently, the heat exchanger was dismantled, and a green viscous material was found deposited on the inside surfaces. This material was approximately ¼ in. in thickness and prevented proper heat flow through the walls of the cooling tubes. Further investigation disclosed large amounts of this green material in the bottom of the lower coil tank.

Analysis of this green material was made by California Research Corporation, a research subsidiary of Standard Oil Company of California. The analysis showed that the material was an organic copper compound (a copper soap) usually formed by oil-derived acids attacking the copper. These acids are usually formed by oxidation of the cooling oil in the presence of copper and moisture which act as catalysts. The resulting soap is in itself a powerful catalyst for the further oxidation of the oil.

The lower coil system was cleaned by an industrial company whose specialty is cleaning large systems and particularly those in oil refineries. This was done by filling the lower coil system with a combination of suitable organic solvents, and allowing it to stand for 24 hours.

After the system had been cleaned, it was filled with Wemco CI oil, which has inhibitors in it to destroy the catalytic action of copper in oxidizing the oil. Although no single characteristic of the oil can be used as a criterion for discarding the oil, the recommendation was that if the oil acidity reached a neutralization number of 0.3 (number of milligrams of koit to neutralize the acidity in one gram of oil), the situation could become dangerous. In addition, it was recommended that moisture be kept out of the oil by forcing dry air over the surface of the oil in the coil tanks. The best solution is to have a sealed system which can be kept under dry nitrogen, but this is not possible at the Berkeley cyclotron.

These oxidation reactions are accelerated at elevated temperatures. For this and other reasons the operating temperatures should be kept low. The start of this reaction at

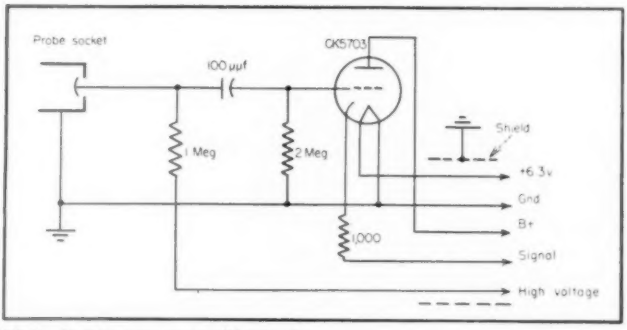

FIG. 3. Probe counter preamplifier circuit

Berkeley was no doubt at the time of the fire that occurred on the bottom of the lower coil tank in 1946. At that time, although the main body of oil did not get hot, there probably was local intense heating at the spot of the fire that started the reaction. However, the oil companies state that these oxidation reactions take place at temperatures that are easily reached by normal operation and that the acidity in particular should be carefully watched.

The magnet at Berkeley has a total of 300 tons of copper in the coils and requires about 750 kilowatts for its excitation. Each of the two coil tanks used about 3,500 gallons of oil in its cooling system and has never been operated with an oil temperature in excess of 55° C.

Chemical Dosimeter for Ionizing Radiations

By JOHN W. KANWISHER*

Atomic Energy Project
The University of Rochester
Rochester, New York

Many personnel dosimeters have been developed for civil defense use. Taplin and Douglas† have developed a colorimetric dosimeter based on the production of hydrochloric acid by a radiation-induced reaction in chloroform. The dosimeter described here utilizes the same effect. However, instead of using a pH-sensitive dye in a two-phase water and chloroform system to indicate dosage by change in color, this system utilizes the change in electrical characteristics caused by production of acid in a chloroform and water solution.

An auxiliary electronic instrument is required to read dosage with this instrument, while the Taplin instrument is directly readable. However, the system does possess several advantages.

One liquid chamber in this instrument is sufficient to measure dosages from 50 to 1,000 roentgens. In contrast, in the Taplin instrument the color change occurs chiefly at one value of dosage. Thus a separate chamber must be used for each dosage to be measured.

This instrument has the light excluded even during dosage reading. The Taplin instrument must be visually observed, and prolonged exposure to light can produce a false reading. In addition, no dye is needed for reading; this eliminates problems caused by the possible instability of the dye over long periods and by the decolorization of the dye by ultraviolet light.

Electronic Reader

The conductivity of a solution of chloroform and water increases as acid is added. Initially, efforts were made to measure the change in conductivity. However, a dosimeter with platinum electrodes—required because any ionizable impurity gives an indication of increased conductivity—was too expensive and too difficult to fabricate. And the equipment required for measurement by the radio-frequency bridge method was too complicated and bulky for field work.

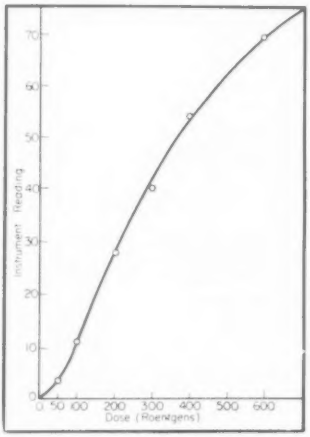

FIG. 2. Calibration curve obtained with earlier model of reader

The results of these first studies showed that an increase in acid concentration in capsules inserted in the turns of a coil in an electric circuit caused both the reactive and resistive components of the coil to change. The degree to which a coil behaves like a perfect inductance is expressed numerically as its figure of merit Q, equal to the reactance divided by the resistance. It was found that Q could be related to acid concentration, and that, when a Q-meter was operated at higher frequencies, the maximum decrease in Q occurred at higher concentrations of acid.

On the basis of these studies, a Q-meter type of instrument was designed. The circuit finally adopted is shown in Fig. 1. The shunt circuit on the meter makes it possible to double the meter range. The meter is

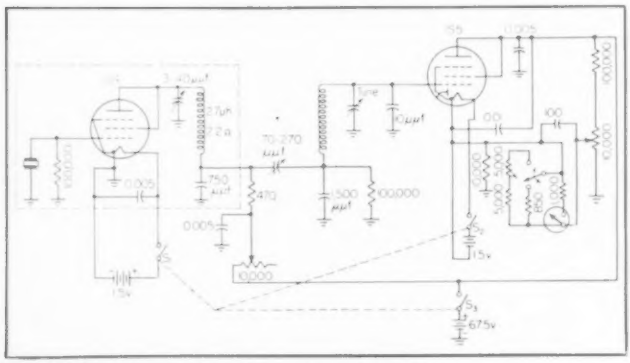

FIG. 1. Circuit diagram of Q-meter type dosimeter reader

* PRESENT ADDRESS: Mather Air Force Base, Sacramento, California.

† G. V. Taplin, C. H. Douglas, NUCLEONICS **6**, No. 6, 66 (1950); see also NUCLEONICS **9**, No. 2, 73 (1951).

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calibrated to read directly in roentgens.

A calibration curve for an early model of this instrument is shown in Fig. 2. This curve shows the desirable property of linearity in the lower dosage regions. Above 600 roentgens, less accuracy is obtained, but the decrease in slope of the curve also makes it possible to obtain a wider range with a given meter.

Dosimeter Construction

The dosimeter capsules are fabricated from 10-mm Pyrex tubing. They are $5\frac{3}{4}$ in. long, and are drawn down to a 3-mm neck on one end and pinched and formed to a flat end on the other. These capsules are filled with three parts chemically pure chloroform from which the preservative alcohol (0.5%) has been removed by washing, and one part double-distilled water, to which 0.15% alcohol has been added to improve the temperature stability of the dosimeter.

Before the neck of the capsule is sealed, the liquids are frozen with liquid nitrogen. This prevents formation of decomposition products during the flame sealing. After sealing, the dosimeters are allowed to thaw on a poorly conducting surface; this prevents cracking.

For protection against breakage and exposure of the solution to light, the capsules are sealed in opaque plastic cases. These cases are made of injection-molded polystyrene.

In actual use, capsules with a filling of known acid concentration are used to calibrate the instrument.

* * *

A more complete description of the experiments and equipment described here can be found in AEC report UR-167 (1951).

U. S., U. K., and Canada Release More Nuclear Data

The United States, the United Kingdom, and Canada have revised the "Declassification Guide" used by the three nations to permit the release of additional data on the nuclear properties of elements necessary in the understanding of low-power nuclear research reactors. The action was taken to speed the development of unclassified reactor technology in the three nations. Design and operating data on such low-power reactors was previously declassified in Nov., 1950.

The revised Guide permits, in addition to publication of thermal-neutron cross sections for Pu^{239}, similar data on xenon-135. This radioactive nucleus, one of the fission products resulting from the fissioning of uranium, is a remarkably effective absorber of thermal neutrons. Information on this property of Xe^{135} will be of basic interest in studies of nuclear structure and will aid in fundamental studies of reactor control.

The nuclear constants declassified are tabulated in the following.

1. Thermal-Neutron Cross Sections for Uranium. (These are currently accepted values in barns for 2,200 meters per second neutrons.)

Thermal-neutron cross section for	U^{235}	U^{238}	*Natural U*
Fission	549	0	3.92
Capture	101	2.80	3.5
Scattering	8.2	8.2	8.2

2. Neutrons per Thermal Neutron Fission. $\nu = 2.5 \pm 0.1$ for U^{235}.

3. Fast Fission Effect. The following are typical values of the fast fission contribution to the reactivity of research reactors: In a reactor of the "CP-2" or "GLEEP" type, 2.9%; in a reactor of the "CP-3" or "ZEEP" type, 3.1%.

The following are values of nuclear constants for natural uranium bombarded by *neutrons above the U^{238} fission threshold* in a heterogeneous uranium reactor, which may be used for illustrative purposes: Average fission cross section = 0.29 barns; average radiative capture cross section = 0.04 barns; average number of neutrons emitted per fission = 2.55; average total cross section = 4.3 barns; average inelastic scattering cross section = 2.47 barns; and average elastic scattering cross section = 1.5 barns.

4. Resonance Absorption Integral. An approximate empirical formula for the effective value of the resonance absorption integral in a uranium lump at room temperature is given by:

$$\int \vartheta_c(E)dE/E = A[1 + \mu(S/M)]$$

where the integral is taken over the resonance energy band given three paragraphs below, S is the lump surface area in cm^2 and M is the mass of the lump in grams.

The constants A and μ depend on the total scattering cross sections associated with each uranium atom. They are, therefore, different for uranium metal or oxide lumps. In fact, A is proportional to the 0.415 power of the scattering cross section associated with each uranium atom up to the scattering cross section of 1,000 barns. For uranium metal, $A = 9.25$ barns and $\mu = 2.67$ gm/cm². For U_3O_8, $\mu = 1.67$ gm/cm². The limiting value of the integral at great dilution is 240 barns.

The approximate temperature dependence of the integral noted previously is given by

$$\int \vartheta_c(E)dE/E = A[1 + \alpha T + \mu(S/M)]$$

where $\alpha \simeq 10^{-4}$ per centigrade degree, the temperature T is in degrees centigrade and A and μ are as previously defined.

The logarithmic width of the resonance energy band $\log_e (E_0/E_1)$ is about 5.6 for uranium metal and 7.3 for U_3O_8 or UO_2.

The inverse diffusion length K_0 for resonance neutrons in uranium metal of density ρ gm/cm³ is $K_0 = 0.022\ \rho\ cm^{-1}$.

5. Plutonium Cross Sections. Average values for the fission and capture cross sections of plutonium-239 for an approximately Maxwellian neutron spectrum with a most probable neutron velocity of 2,200 meters per second are 664 barns and 361 barns, respectively.

Neutrons per thermal neutron fission of $Pu^{239} = 3.0 \pm 0.1$.

6. Xenon. Thermal-neutron absorption cross section of $Xe^{135} = 3.5 \times 10^6$ barns.

TECHNICAL BRIEFS

• **Combustion studies** of tetraethyl lead, the antiknock compound added to gasoline, will be aided by addition of C^{14} as a tracer. The synthesis has been accomplished by scientists at Battelle Memorial Institute, Columbus, Ohio.

• **Keeping-qualities** of vitamin B-12 capsules can be studied without complicated analyses if the vitamin is labeled with Co^{60}. C. Rosenblum and D. T. Woodbury of Merck and Co., Rahway, N. J., report that the vitamin possesses considerable stability.

• **Alloys** containing lead and copper are much more susceptible to contamination by I^{131} than galvanized iron or steel. Research on adsorption of radioactivity by metals is being carried out at Johns Hopkins University, Baltimore, Md.

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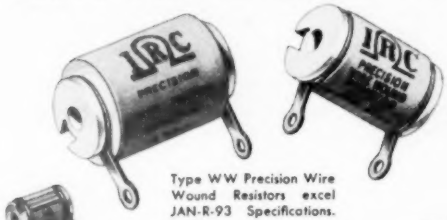

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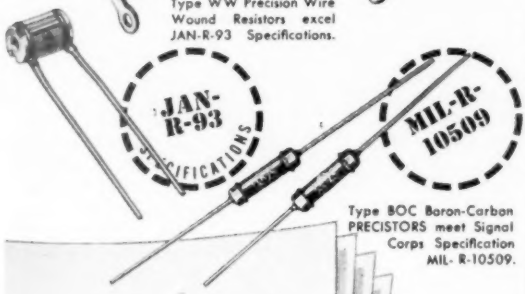
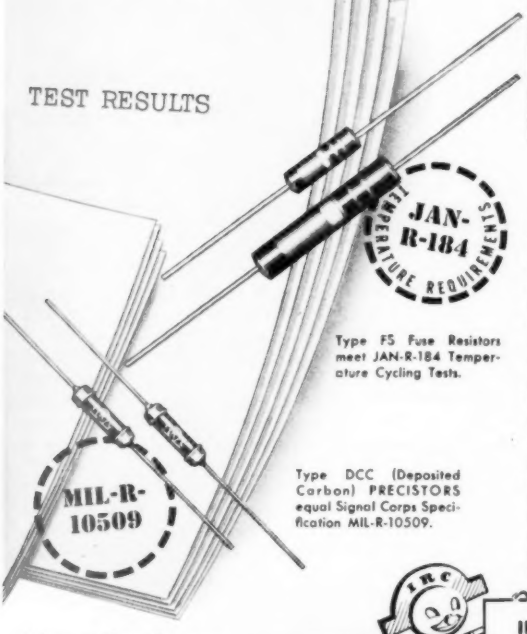


Type BOC Boron-Carbon PRECISTORS meet Signal Corps Specification MIL-R-10509.

TEST RESULTS

	Original Resist.	1st Cycle % Chge	2nd Cycle % Chge	3rd Cycle % Chge	4th Cycle % Chge	Resist. at End of 100 hrs. load	Total % Chge	% Chge from Last Temp. Cycle to End of 100 hrs. load %	Resistance Chge at End of 100 Hrs. Load only % (no cycling)
1	100,010	+ .04	+ .04	+ .05	+ .05	100,050	+ .04	− .01	100,040 − .02
2	100,000	+ .03	+ .04	+ .03	+ .05	100,060	+ .06	+ .01	100,000 0
3	100,000	+ .01	+ .02	+ .02	+ .05	100,000	0	+ .05	100,050 − .02
4	100,000	+ .02	0	+ .02	+ .02	100,000	0	− .02	100,040 − .01
5	100,010	+ .03	+ .04	+ .04	+ .05	100,000	0	− .05	100,030 − .03
6	100,000	0	+ .03	+ .04	+ .04	100,100	+ .1	+ .06	99,980 0
7	100,000	+ .04	+ .05	+ .04	+ .04	100,070	+ .07	+ .03	100,000 0
8	100,000	+ .03	+ .05	+ .05	+ .05	100,050	+ .05	0	100,000 0
9	100,000	+ .04	+ .03	+ .05	+ .04	100,010	+ .01	− .03	100,050 0
10	100,000	+ .02	+ .02	+ .02	+ .04	100,010	+ .01	− .03	100,000 0
11	100,000	0	+ .01	+ .01	+ .03	100,000	0	− .03	

Severe cycling and 100-hour load tests resulted in virtually zero changes in resistance. Other rigid tests prove Type WW's high mechanical strength, freedom from shorting, resistance to high humidity.



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BOOKS

Energy Sources—The Wealth of the World, by Eugene Ayres and Charles A. Scarlott, McGraw-Hill Book Co., Inc., New York, 1952, vii + 344 pages, $5.

This is the best and most comprehensive book on the subject that has come out to date. Respectively the technical assistant to the executive vice president, Gulf Research and Development Company, and editor of the *Westinghouse Engineer*, the authors have excellent backgrounds of technical writing and are unusually skillful in putting technical information down in readable and usable fashion. They have had access to a great fund of information, have long dealt with energy supplies, their transformation, transportation and utilization; furthermore, they portray an undoubted enthusiasm for their subject.

The first brief chapter, *Energy—Our Priceless Heritage*, adequately sets the frame of reference for the treatise. It tells not only of the necessity of adequate energy supplies but of the channels of use and the desirable areas of emphasis in meeting future problems. The next chapter is a short, well-highlighted survey of pertinent points of the prehistoric formation of mineral fuels and the principal impact of fuels and the utilization of energy in the shaping of history. From there on through the succeeding 19 chapters the book gets down to the specific information of sources and uses of energy, predictions of future trends, and suggestions for future activities to assure posterity that its reservoir of energy will not run dry.

The treatment is well balanced throughout, no facets of the subject being ignored and few showing signs of being slighted. Coal comes in for extensive treatment. Wood and other forms of vegetation are carefully considered. Water power has its adequate day, and wind and tidal power are given rational evaluation. The direct utilization of solar energy is treated comprehensively in most of its aspects. In discussing nuclear energy, the authors have succeeded in avoiding the common habit of labeling it the panacea of the future. They present the over-all facts known to date and express appropriate reserve as to its ability to solve the major energy problems of the future.

The portions concerning utilization are comprehensive and well presented. The means of handling and processing fuels, past, present, and prospective, are dealt with as thoroughly as could be expected in a book of this size. Of particular importance are the discussions of inherent losses and preventable inefficiencies in acquiring, transporting, converting, and utilizing various fuels in various devices. The book is replete with tables of energy-system efficiencies. Many of the data are very revealing on the inefficiencies of our practices.

The text ends with a chapter called the *Energy Balance Sheet*, which gives a clean-cut summary of the over-all present and future situation.

Besides numerous charts, tables, graphs and excellent illustrations, there are three appendixes. The first appendix summarizes the more important data on energy sources. The second presents adequately complete data on the heat value of a great variety of fuels and the usual energy conversion factors for heat, energy, and work. The third appendix is a 220-item bibliography.

Balanced against the items of enthusiasm are three items that might be subject to a small bit of criticism. To make the text readable, the authors may have overdone the matter a little; this may be a source of slight irritation for the person with a strictly scientific or technical interest. The emphasis on information and interpretation has perhaps been unduly heavy for the United States. The rest of the world might well have received more attention, even though data are somewhat scanty and the space was limited. Lastly, there was inadequate consideration of the tremendous potentialities of solar energy through the medium of artificial photosynthesis. Even though artificial synthesis has not yet been accomplished, it still is an item that can hardly be overlooked in the crystal ball. These criticisms, if such they are, are only minor and should not deter anyone who has the slightest interest in energy sources from perusing this truly estimable volume.

—C. G. Furnas, *Director*
Cornell Aeronautical Laboratory
Buffalo, New York

Handbook of Dangerous Materials, by N. Irving Sax, assisted by W. W. Schultz and M. J. O'Herin, Reinhold Publishing Corp., New York, 1951, vii + 848 pages, $15.

This volume is a digest of literature concerning the potential hazards in handling some 5,000 materials. Its purpose is to present the material in a readily accessible form to industrial personnel not specially trained in industrial hygiene, physics or chemistry.

The greater part of the contents is devoted to an alphabetically arranged list of the dangerous materials, giving formulas, important physical data, hazardous properties, storage and handling recommendations, and shipping regulations. This section fills a great need for a single reference available to anyone responsible for the health and safety of workers required to handle dangerous materials. The references to existing shipping regulations should be very useful. It is unfortunate that a lack of uniformity of storage and handling regulations among various municipalities and states does not permit similar references to such statutes and codes. There are, in addition, sections on *Explosives, Fungus Diseases and Fungicides, Radiation and Radiation Hazards* and *Shipping Regulations.*

For users of most of the dangerous materials listed in the main section of the book, specific recommendations are given. The proper method of storage is described with any necessary handling precautions, including ventillation and protective equipment such as gloves or respirators. In the listings of radioactive materials, the user is referred to the section on *Radiation.* The latter section, however, does not treat the subject in handbook style and the untrained user, toward whom the volume is purported to be directed, is given no specific instructions on handling or storing the various radioactive substances.

A review of those materials of particular interest in the nucleonics field includes, in addition to the radioactive materials, certain others used in association, such as beryllium and zirconium. The subject of beryllium has been well covered. The authors were correct in stating that no shipping regulations existed at the time of publication. Packaging restrictions, however, have been placed on beryllium since then (ICC Reg. §73.378). Thorium in powdered form is stated

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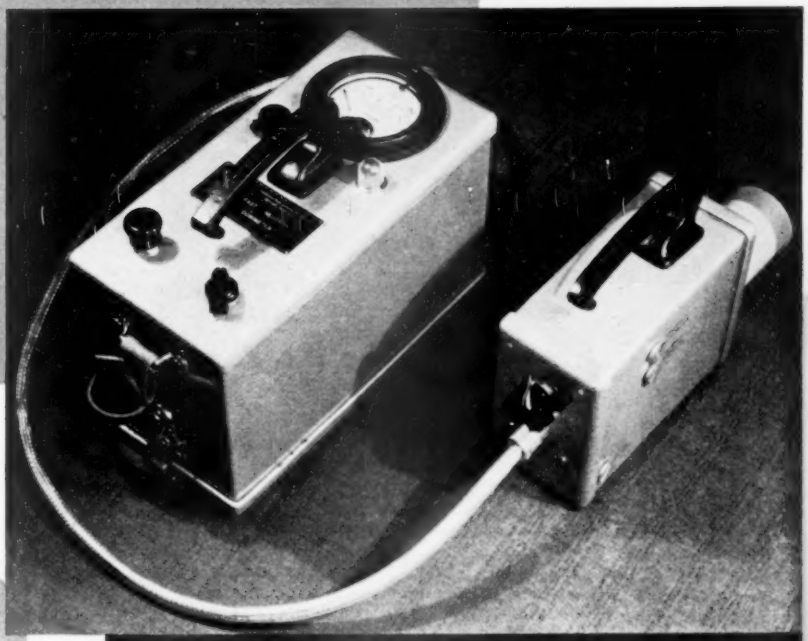

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to be a flammable solid and a dangerous fire hazard. No mention is made of the fact that spontaneous ignition is likely if the material is not properly packaged. The same is true of uranium, zirconium, vanadium, titanium, magnesium, and aluminum, although not mentioned.

In the first section of the handbook, established facts are not distinguished from opinions as to the toxicity of various materials. A few of the opinions expressed are controversal. A system of references to source material would correct this but might become unwieldy in such a large volume.

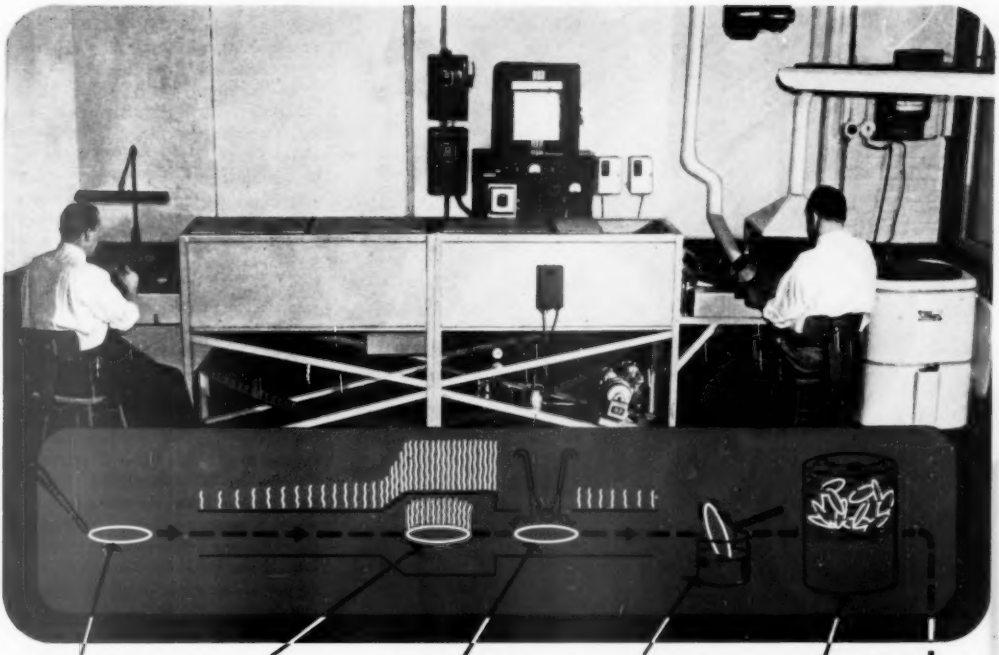
The section of most interest to NUCLEONICS readers is, naturally, the section on *Radiation and Radiation Hazards*, which gives a comprehensive review of the principles of production and properties of radiation, as well as a discussion of the various types and degrees of hazard involved. Monitoring instruments and methods, shielding, waste disposal, handling and shipping are all covered with references to original sources.

A lucid and complete explanation of the Segrè chart of the nuclides with examples of its use are given. The latest chart is included in its entirety.

The various processes of radioactive decay and the radiations emitted are described with examples and energy level diagrams. The interactions of radiation with matter and the principles of absorption related to shielding problems are discussed. Electromagnetic radiation, alpha and beta particles, and neutrons are each discussed in separate subsections, with curves of actual measurements shown for alpha, beta, proton, gamma, and X-radiation.

Considerable attention has been paid to X-ray shielding. There is some question whether this subject should appear in a book devoted to dangerous materials. Regardless of this, it is doubtful if any but a qualified expert should be called upon to decide upon the required shielding of X-ray equipment.

It is unfortunate that the authors draw to such a large extent upon obsolete sources. For example, the X-ray shielding tables shown are from the ASA War Standard Safety Code for Industrial X-Rays which is based on the old maximum permissible dose rate value of 100 mr per day. The current value, as correctly quoted by the authors elsewhere, is 300 mr per week. The table of "Gamma Ray Dose Rate from Radium" published by Mayneord



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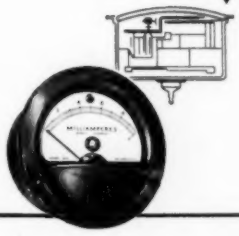

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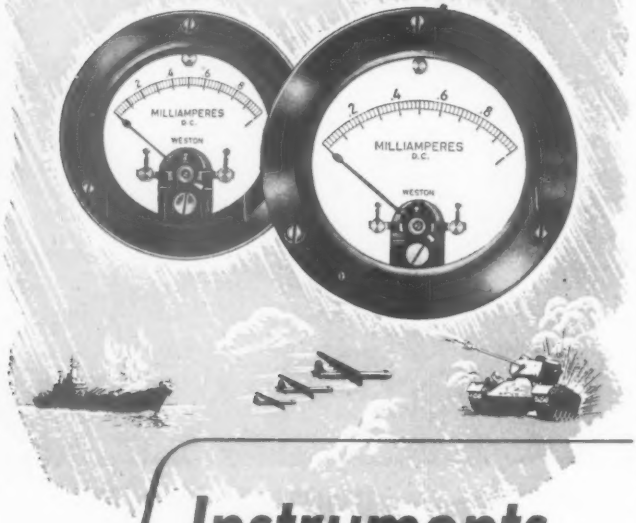

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WESTON *Instruments*

and Roberts in 1937 and reproduced in this book is one of many such measurements reported in the literature. The value almost universally used currently is higher than the one given.

There is a degree of unbalance in the section on *Radiation* which tends to over-emphasize certain phases of the subject of doubtful value or importance while overlooking some important ones. It would seem that plant managers, safety inspectors, and foremen would be interested, for example, in the detection and measurement of radioactive gases and dusts that might be potential inhalation hazards. This subject is ignored in the brief treatment of internal hazards which covers about one page. On the other hand, the chart of nuclides and its explanation, which takes 27 pages, or the description of ionization-chamber and counter-tube characteristics, to which 8 pages are devoted, although complete and well presented, are probably of questionable interest to such a group. Although the ICC, Postal, and Railway Express regulations are quoted, those of the Civil Aeronautics Board have been omitted. Experience has shown that all of these regulations require considerable interpretation in practice, although the Handbook does not cover this problem.

The discussions of atomic theory, nuclear particles and radiations with the explanation of their absorption and scattering are well done. It is highly questionable, however, whether this handbook is the proper place for such material. The authors justify the section on *Radiation and Radiation Hazards* by stating that its purpose is "to review a variety of radiation protection problems and to suggest practical procedures." They fail, however, to carry out the plan. The subject of radiation and contamination surveying is covered very superficially, and personnel monitoring is not mentioned. The most widely used medium for radiation detection, the photographic film, is not discussed at all.

The basic objective of this volume is certainly sound. With the elimination of certain shortcomings frequently found in first editions of handbooks, it will undoubtedly prove to be a valuable adjunct to the library of anyone responsible for the health and safety of industrial personnel.

—Hanson Blatz
Chief, Radiation Branch
Health and Safety Division
U. S. Atomic Energy Commission
New York Operations Office

BOOKS RECEIVED

Radiocarbon Dating, by Willard F. Libby. The University of Chicago Press, Chicago, Ill., 1952. vii + 124 pages, $3.50. *(To be reviewed.)*

French-English Science Dictionary (new second edition), by Louis DeVries, McGraw-Hill Book Co., Inc., New York, 1951, 596 pages, $6.50.

The first edition of this popular science dictionary appeared in 1940. Minor revisions to the original text have been made in the new edition, and new terms have been added. This new second edition carries the subtitle "for students in agricultural, biological, and physical sciences."

OTHER LITERATURE

Energy and Angle Distribution of the Photoprotons from Deuterium (National Bureau of Standards Circular 515), by Martin Wiener. A 13-page paper giving relativistically exact formulas and graphs describing the energy-angle relationship. Data are included for converting angles from the laboratory system of reference, employed in experimental work, to the center-of-mass system, used chiefly in theoretical analysis. *GPO, Washington 25, D. C., $0.15.*

Radiological Monitoring Methods and Instruments (National Bureau of Standards Handbook 51). According to the Subcommittee on Monitoring Methods and Instruments of the National Committee on Radiation Protection which prepared it, this 33-page report "represents an attempt to establish some basic guides for methods of determining radiation hazards and selecting suitable instruments for measuring them." This group has acknowledged that specific recommendations may become obsolete as new instrument designs are introduced and have, therefore, considered only types proved useful in practice. Monitoring information is included for alphas, betas, gamma and X-radiation, and neutrons. There are chapters on radiation detectors, measuring instruments, personnel-monitoring instruments, instrument requirements, and radiation-survey methods. An appendix contains recommendations for air-sampling, water-sample analysis, and alpha- and beta-particle counting. *GPO, Washington 25, D. C., $0.15.*

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NUCLEONIC EVENTS

AEC Invites More Proposals for Industry Reactors; Gives Okay to Dow-Detroit Edison for Further Study

New proposals from private industry for preliminary studies of the practicability of privately-financed construction and operation of reactors are being invited by the Atomic Energy Commission. In an announcement of its readiness to consider new feasibility studies, the Commission set June 1, 1952, as its deadline for receipt of the proposals.

At least one industry group has decided that prospects for the development and economic operation of its own reactor are sufficiently promising for it to continue to invest its own money for specific study of the problem, and the Commission has accepted the group's study proposal. This is the one submitted jointly by the Dow Chemical Company and the Detroit Edison Company. Calling it "an attractive proposal," the AEC has negotiated with this group for further study to include additional research and development work by both the companies and AEC laboratories.

Quarter Million Investment

The study will continue for one year and will be financed jointly by the Dow-Detroit Edison group and the AEC. The two companies estimate their cost of the extended studies at about $250,000. Work to be done by the Commission in this area of research, much of which is already under way or scheduled, may run as high as $750,000. The study will involve both reactors and chemical separation processes, but will not provide a final reactor design.

Arrangements for New Proposals

When the Atomic Energy Commission completed feasibility-study contracts last spring with four groups of companies which expressed interest in building and operating reactors (NU, Feb. '51, p. 86; June '51, p. 42; July '51, p. 2), it shut out the possibility of other industry studies because AEC technical manpower available to assist such groups was limited. However, as evidenced by its invitation for additional proposals, the Commission is now in a better position to give interested companies the technical assistance required.

The pattern for previous industry-reactor proposals have included three phases: (1) feasibility study, (2) design, and (3) construction and operation. Agreements with new groups are expected to follow the same pattern. As outlined by AEC, the main goals of the studies include specifically: (a) determination of the engineering feasibility of design, construction, and operation of a reactor by private enterprise, (b) examination of the economic and technical aspects of building such a reactor, (c) measure of the research and development work needed before such a reactor project could be undertaken, and (d) recommendation to the AEC what should be the specific role of industry in carrying out such a reactor project. The power produced by the reactor would, it is expected, belong to the group that financed the project, but all isotopes and fissionable materials produced as by-products would belong to the government.

As under present agreements, all costs on the first phase will be borne by the companies except the time of the AEC and its contractors needed for consultation and information services. The commission will decide on the distribution of reports and on the disposition of all inventions and discoveries made in the course of the work.

Security clearances will be granted, after an FBI investigation, to a sufficient number of qualified industry representatives to carry out the study. Experience indicates this to be about 10 persons per company or group.

Report Status

In interim reports received by the Commission from the four groups previously mentioned, a "cautious optimism" was displayed that the "technical and cost factors involved will be solved eventually." The AEC action in connection with the Dow-Detroit Edison group does not constitute a selection among the four. Full consideration will be given by the Commission to the other proposals when the sponsoring companies submit final reports on their preliminary studies shortly after the middle of the year.

All four groups are studying several general types of reactors.

$10- to $15-Million Nuclear-Power Reactor to Compete with Conventional Power Is Goal of New Company

It should be possible to build, for between $10,000,000 and $15,000,000, a nuclear reactor that will produce 100,000 kw of useful power, Dr. Karl Cohen predicted last month in announcing the establishment of Walter Kidde Nuclear Laboratories, Inc.: design of such a reactor, is a goal of the new company of which Dr. Cohen has been named vice president. The primary objective of the laboratories will be the development of commercial nuclear power.

Dr. Cohen, former director of the Atomic Energy Division of The H. K. Ferguson Company and Manhattan Project scientist whose theoretical work in isotope separation was a major contribution to the development of the K-25 gaseous-diffusion plant at Oak Ridge, will direct the laboratories' technical activities.

The new company was founded, Dr. Cohen said, on the conviction that "within a few years" power from atomic fission will be competitive with power from coal or oil-fired boilers. "Although we cannot discuss specific atomic-reactor costs," he explained, "we can set limits within which an atomic plant can compete with coal-fired plants."

He then went on to estimate the additional investment tolerable if most of the fuel charge could be saved. "Consider," he said, "a 100,000-kw coal-power plant operating at 50% load factor, with coal at $10 per ton. If the cost of fuel were completely

COMING NUCLEAR CONFERENCES AND COURSES

Subject	Time and Place	Sponsor	To enroll, write	Remarks
Conference on Medium-Energy Nuclear Physics	June 5–7 Pittsburgh, Pa.	University of Pittsburgh	Dr. D. Halliday, Head Department of Physics University of Pittsburgh Pittsburgh 13, Pa.	Program limited to studies of nuclei with $A < 4$, using projectiles accelerated in electrostatic generators or conventional cyclotrons
Course in Techniques of Using Radioisotopes in Research	June 9–July 4 Oak Ridge, Tenn. *Repeated:* July 7–Aug. 1 Aug. 11–Sept. 5	Oak Ridge Institute of Nuclear Studies	Dr. Ralph T. Overman, Chairman Special Training Division Oak Ridge Institute of Nuclear Studies Oak Ridge, Tenn.	Each four-week course is open to 32 participants
Symposium on Electron Transfer and Isotopic Reactions	June 11–13 Notre Dame, Ind.	American Chemical Society's Division of Physical and Inorganic Chemistry and American Physical Society's Division of Chemical Physics	Dr. James V. Quagliano Department of Chemistry University of Notre Dame Notre Dame, Ind.	Registration $2.50 for ACS and APS members, $5 for non-members; additional charge for reprints. Room reservations made if requested before May 31. Registration limited to 200. See page 74 for details
Conference on the Use of Isotopes in Plant and Animal Research	June 12–14 Manhattan, Kan.	Kansas State College, Argonne National Laboratory, and U. S. AEC Isotopes Division	Dr. A. B. Cardwell Department of Physics Kansas State College Manhattan, Kan.	No registration fee; information on living accommodations sent on request. See page 76 for details
Nuclear Chemistry Section of Gordon Research Conferences	June 23–27 New Hampton School, New Hampton, N. H.	American Association for the Advancement of Science	Dr. W. George Parks, Director Department of Chemistry University of Rhode Island Kingston, R. I.	Attendance limited to 100; $15 registration fee plus $10 subsistence deposit requested. Glenn T. Seaborg and C. D. Coryell are co-chairmen of sessions
Atomic Energy Institute (Industrial and Legal Problems)	June 26–28 Ann Arbor, Mich.	University of Michigan Law School and Michigan Memorial-Phoenix Project	Atomic Energy Institute Law School University of Michigan Ann Arbor, Mich.	Registration $15, includes copy of proceedings. See page 76 for details
Fourth Annual Oak Ridge Symposium (Topic: "The Role of Atomic Energy in Agricultural Research")	Aug. 25–29 Oak Ridge, Tenn.	University of Tennessee-Atomic Energy Commission Agricultural Research Program	University Relations Division Oak Ridge Institute of Nuclear Studies P. O. Box 117 Oak Ridge, Tenn.	Sessions on plant and animal studies with atomic-energy research tools, including carbon-14. Under auspices of Oak Ridge Institute of Nuclear Studies and the Oak Ridge National Laboratory
International Conference on Beta and Gamma Radioactivity	Sept. 1–6 Amsterdam, The Netherlands	Netherlands Physical Society and the International Union of Pure and Applied Physics	Prof. Dr. J. de Boer Bunsenstraat 98 Amsterdam-O, The Netherlands	Preliminary program will appear in NUCLEONICS next month
Seventh National Chemical Exposition (featuring exhibits and program on industrial uses of atomic energy)	Sept. 9–13 Chicago Coliseum, Chicago, Ill.	American Chemical Society	National Chemical Exposition Chicago Section, American Chemical Society 86 East Randolph Street Chicago 1, Ill.	Details and speakers to be announced later for full-day program
Third Instruments and Measurements Conference and Exhibition	Conference, Sept. 22–25 Exhibition, Sept. 23–30 Stockholm, Sweden	Royal Swedish Academy of Engineering Sciences and Association of Technical Physicists	Mr. Yngve Axner Kungl. Tekniska Högskolan Stockholm 70, Sweden	Membership fee: 25 Swedish Crowns without, 40 with, Transactions of conference. Large group of papers on "Methods of Measurement in Nuclear Physics and Radioactivity." Official languages of conference are English, German, and French

eliminated, the plant investment could increase by $12,000,000, with no increase in power cost. A fraction of this $12,000,000 would thereupon be available for the additional cost of reactor and processing plant. This additional investment depends on the existing price of coal and on the load factor of the power plant. For example, with coal at $15 per ton and a load factor of 80%, the amount of additional investment would be about $29,000,000.

"The tolerable investment range for reactor and other related special equipment appears to be between $10,000,000 to $15,000,000 for a 100,000-kw plant. Nobody has built a nuclear-power plant for this price yet. Reactors of comparable heat output constructed for the Atomic Energy Commission are known to cost considerably more than this. However, the high investment for government production plants, which have costly features resulting from military requirements, may not necessarily carry over to commercial practice. Commercial designers, unhampered by military considerations and spurred by profit incentives, may be able to reduce costs substantially. Lower-cost reactors are the key to economical atomic power. . . . A low-cost reactor for commercial use will be an important objective of the Walter Kidde Nuclear Laboratories."

Dr. Cohen will be assisted by William I. Thompson, who has been appointed chief engineer of the laboratory. Dr. Thompson was associated with isotope-separation process design at Oak Ridge and in 1948 became chief engineer in Dr. Cohen's division in the Ferguson Company.

In addition to its development work in nuclear energy, Walter Kidde Nuclear Laboratories, Inc., will make its services available to other organizations interested in the design of nuclear-power plants or in applications of nuclear technology to their products.

Sponsors of the new project, which will have offices at 140 Cedar Street, New York, and laboratories in Long Island, are Walter Kidde & Company, Inc., manufacturers of fire-protection systems and pneumatic devices for aircraft and marine application, and Walter Kidde Constructors, Inc., an engineering and construction firm.

The organization has an initial staff of 30 scientists and engineers, and present plans are to expand this number to 100 during the next year or two.

Materials Testing Reactor Goes "Critical"

The new $18,000,000 materials testing reactor (MTR), one of the principal components of the AEC's National Reactor Testing Station at Idaho Falls, Idaho, is now in operation. It became "critical" on March 31, and is now being brought up gradually to full power. Operating contractor of the MTR is the Phillips Petroleum Co., of Bartlesville, Okla.

As the name implies, the MTR will provide much needed facilities for determining how radiation affects materials considered for use in the structures, cooling systems, and shields of new reactors. It contains over 100 ports in which specimens can be exposed to neutron bombardment. Although designed to operate primarily on thermal, or slow, neutrons, it can also produce neutrons of intermediate and fast energies. Many new design features are incorporated. Its fuel is enriched uranium in units designed for rapid heat transfer, and it is cooled by water circulating at high velocity.

Excavation for MTR was started in May, 1950, by the Fluor Corporation, Los Angeles, which was the major construction contractor. Research and development work was done by both Argonne and Oak Ridge National Laboratories, with engineering design by the Blaw Knox Construction Co.

Electron Transfer Subject of Notre Dame Symposium

The American Chemical Society and the American Physical Society have announced that they will jointly sponsor a Symposium on Electron Transfer and Isotopic Reactions to be held June 11–13 at the University of Notre Dame, Notre Dame, Indiana.

As presently planned, the program will include three general introductory papers (June 11, morning; John R. Platt, University of Chicago, presiding); four papers on electron processes in the gas phase (June 11, afternoon; John L. Magee, University of Notre Dame, presiding); nine papers on electron transfer reactions in solution (June 12; W. F. Libby, University of Chicago, presiding at morning session; R. W. Dodson, Brookhaven National Laboratory, at evening session); five papers on isotope effects on chemical reaction rates (June 13, morning); and three papers on kinetic and equilibrium effects of isotopic substitution (June 13, afternoon; Jacob Bigeleisen, Brookhaven National Laboratory, presiding all day).

For additional information, see tabulation on page 73.

AEC Establishes Office of Industrial Cooperation

On May 1 the Atomic Energy Commission set up an Office of Industrial Cooperation with "positive responsibility" to foster wider industrial participation in the AEC program and in development of a "more normal competitive approach" to certain areas of its business. William L. Davidson, former director of physical research of The B. F. Goodrich Company, has been named to head up the work of the office, which is a responsibility of the AEC's general manager, M. W. Boyer.

Dr. Davidson, a 36-year-old physicist, is a graduate of the first class to attend Oak Ridge School of Reactor Technology in 1950.

VA Hospitals Seek Isotope Job Applicants

The U. S. Civil Service Commission last month announced it is seeking qualified persons to fill the positions of physicist, chemist, biologist, and biochemist in connection with radioisotope work in Veterans Administration Hospitals and Centers throughout the country. Salaries range from $4,205 to $9,600 a year.

Applications will be accepted until further notice by the Executive Secretary, Central Board of U. S. Civil Service Examiners, Veterans Administration, Washington 25, D. C.

AEC Surveying Ohio Valley for Gaseous-Diffusion Plant

The Atomic Energy Commission last month confirmed that it is surveying prospective locations for a site for a new gaseous-diffusion plant and that studies presently are being concentrated in the Ohio River Valley. According to AEC's General Manager, M. W. Boyer, the Ohio area offers the availability of both water and potential power at reasonable cost in quantities needed for such a plant.

To cost in the neighborhood of $1,000,000,000, the plant is planned

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DPi produces a complete line of these organic fluids for fractionating pumps, uncompartmented oil diffusion pumps, and oil ejector pumps. In addition, several of these fluids are desirable for various non-pumping applications, such as for differential manometers, immersion lenses, vibration damping, constant temperature baths, and other applications. Certain others are especially suitable for lubrication. DPi also manufactures a group of fine instrument lubricants under the trade-mark "Myvalube."

For complete information on any of these fluids, write to *Distillation Products Industries,* Vacuum Equipment Department, 781 Ridge Road West, Rochester 3, N.Y. (Division of Eastman Kodak Company).

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Silicone Pump Fluid, Type DC-703, is recommended for pumping systems without automatic safety controls, where there is danger of exposure at operating temperature to bursts of gas at pressures above 1 mm Hg.

Myvane-20 Pump Fluid is a hydrocarbon oil recommended for very large fractionating pumps where ultimate vacuum of 1×10^{-5} mm Hg is sufficient.

FOR UNCOMPARTMENTED OIL DIFFUSION PUMPS

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Myvane-20 Pump Fluid gives an ultimate vacuum in MC Pumps of about 8×10^{-6} mm Hg.

Silicone Pump Fluid, Type DC-702, may be used in DPi's MB and VMB Booster Pumps where exposure to atmospheric pressure while hot is difficult to avoid.

FOR OIL EJECTOR PUMPS

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Myvane-20 Pump Fluid is recommended for use in KB and KS Pumps to attain an ultimate vacuum of one micron Hg or less against forepressures up to 2 mm Hg.

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as part of President Truman's five-year atomic-energy-program expansion announced early this year (NU, Mar. '52, p. 75). This production facility will exceed in size the Oak Ridge gaseous-diffusion plant and the one presently under construction at Paducah, Kentucky. The site sought will occupy 5,000 to 6,000 acres.

Preliminary designs call for a plant using about 1,800,000 kw of power and requiring 4,000 to 5,000 operating workers. Approximately 34,000 construction workers would be needed during the peak of construction, for a period lasting about two months. In the 3½ to 4 years it would take to build the plant, there would be only one year in which more than 17,000 construction workers would be needed.

To supply the plant's power, electric generating facilities would be built either by private industry or the government. Interim power requirements, which would gradually increase to 400,000 kw, would be used for a period of 12 to 18 months and would then be relinquished as the permanent power source is brought to completion.

The Commission made it clear that surveys of a number of areas in the United States have been conducted but that no decision on a site has yet been made. The decision will probably not be announced, in any case, until Congress approves the AEC expansion program which is still in the draft stage. One of the things the Commission is trying to avoid in connection with choosing the projected site is construction of a government owned and operated community.

AEC Releases Details on Isotron Isotope Separator

The Atomic Energy Commission last month declassified details of a wartime-developed machine called the isotron separator, together with information on the isotope-separation experiments carried out with it. Abandoned in 1943 for more practical ways of producing isotopes in the quantities needed in the classified work of the AEC, the method, according to Commission spokesmen, may be valuable to scientists in other types of nuclear-physics research.

The separator was developed at Princeton University in 1941–42 during investigations of electromagnetic methods of separating uranium-235 from uranium-238. It was deliberately given the meaningless name of "isotron" because of the wartime secrecy involved.

The machine may be used either to separate isotopes or, as a mass spectrometer, to measure masses of ions, using the "time of flight" principle.

Speakers Announced for Kansas Isotopes Conference

The speakers and topics to be discussed at the Conference on the Use of Isotopes in Plant and Animal Research to be held at Kansas State College, Manhattan, Kansas, from June 12–14, were announced last month as follows:

June 12: *Survey of present uses of isotopes in agriculture*, by Paul C. Aebersold, AEC Isotopes Division; *A typical tracer experiment*, by R. H. McFarland and R. E. Hein, Kansas State College; *The research program of the Atomic Energy Commission—Biology Branch*, by N. Edward Tolbert, AEC; *Radioisotopes in fertilizer usage, soil fertility, and plant nutrition*, by Sterling B. Hendricks, U. S. Department of Agriculture; *Translocation of radioactive mineral nutrients in plants*, by Odin Biddulph, State College of Washington; *Measurement of phosphorus on the surface of soil particles and its relationship to the plant-available phosphorus*, by Sterling R. Olsen, Colorado A & M College; *Studies of biological nitrogen fixation with* N^{15}, by R. H. Burris, University of Wisconsin; and *Genetical effects of thermal neutron irradiation in plants*, by E. F. Frolik, University of Nebraska.

June 13: *Metabolism procedures and their significance in radioisotope studies with farm animals*, by Sam L. Hansard, University of Tennessee–AEC Project; *Use of* P^{32} *and* C^{14} *as tracers in research on metabolism and food utilization, especially in dairy cows*, by Max Kleiber, University of California; *Hormonal and nutritional studies in animals*, L. F. Wolterink, Michigan State College; *Poultry studies with isotopes*, by R. E. Clegg, Kansas State College; *Studies of insects and insecticides with tracers*, by Paul A. Dahm, Kansas State College; *Utilization of* C^{14} *in plant research studies*, by John Skok, Argonne National Laboratory; *Studies in photosynthesis with isotopes*, by Melvin Calvin, University of California; *Utilization of* C^{14} *in carbohydrate metabolism studies*, by S. Aronoff, Iowa State College; and *Effect of radiations on the growth and development of plants*, by N. J. Scully, Argonne National Laboratory.

June 14: *Biosynthetic radioactive products available for research*, by F. E. Kelsey, Nuclear Instrument and Chemical Corp. Following the latter paper, there will be an open forum on techniques, equipment, health and safety, and general problems associated with research involving isotopes, with introductory remarks by G. William Morgan, AEC Isotopes Division.

Information on registration, etc., appears on page 73.

Michigan Law School Plans Atomic Energy Conference

The legal and industrial problems arising from the fast-growing atomic-energy industry will be the subject of the University of Michigan Law School's Fifth Annual Summer Institute, to be held in Ann Arbor, June 26–28. Authorities from industry and government will participate in lectures and panel discussions aimed at answering the questions facing businessmen and lawyers in the atomic age.

The institute, given in cooperation with the Michigan Memorial-Phoenix Project, will take up such questions as private capital for nuclear power, reactor developments, production and use of radioisotopes, labor-management relations, patent policies, security and censorship, radiation hazards to life and properties, and contract problems.

Special features of the Institute will include tours of the University's atomic-energy laboratories and accelerators, and an exhibit of the Traveling Measurements Unit of the Public Health Service.

See page 73 for other information.

IN BRIEF

• **Contractor's fee.** Recent House Appropriations Committee hearings have revealed that F. H. McGraw & Co., Hartford, Conn., is scheduled to get a fee of $1,592,000 for its work as general contractor for the new AEC gaseous-diffusion plant at Paducah, Ky.

• **India's progress.** *The Indian Atomic Energy Commission reports that the monazite factory being built in the Travancore State is going into operation soon. The government-owned company, Indian Rare Earths, Ltd., will manage*

the plant, which is capable of processing 1,500 tons of the mineral a year. The Commission is considering construction of another factory to produce thorium and uranium compounds.

• **Radiation physics course.** The Engineering Evening School of Georgia Institute of Technology early this year initiated a 36-hour adult-education course in Radiation Physics. The first course attracted thirty people. A second course is now in session. The interest shown indicates that the demand for this training will require one such course each quarter with a possible advanced course in the future. Elementary nuclear physics, effects of radiation, radiation instruments, and radiological defense are covered.

• **Australian uranium.** *As a result of a trip to Radium Hill and Rum Jungle, uranium-ore-bearing territories in Australia, Jesse Johnson, director of the AEC's Raw Materials Division, has offered the Australian Cabinet about $3.50 a pound for uranium oxide mined from these areas. A report to a Cabinet committee indicated that Radium Hill could produce uranium oxide in commercial quantities within a year.*

• **Anglo-American cooperation.** The *New York Herald Tribune* made the editorial comment recently that one form of nuclear fission that "proved costly to the free world was the splitting of American and British research on atomic subjects." What prompted it was the proposal made in London recently by James B. Conant, president of Harvard University. He urged that the United States and Great Britain set up a joint commission to prepare for a resumption of partnership in technical matters, including nuclear physics.

• **Employment figures.** Over 7,000 persons will be employed in permanent operation of the AEC's Savannah River Plant in South Carolina when it is completed. At present, 25,000 are engaged in construction activity at the project, with peak employment of construction workers expected to reach 45,000 in September.

NUCLEAR NEWSMAKERS

Clarence L. Karl, formerly manager of the AEC's St. Louis (Mo.) Area, has been named manager of the AEC's Fernald (Ohio) area, site of the new

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using a ¼" crystal cap with a 1 microcurie source of I^{131} at 15 centimeters.

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Easily interchanged pole pieces allow a wide variety of field patterns with just one electromagnet. Separating yoke halves, accurate mounting faces and large access openings provide simplicity of experimental set-up. Air gap is easily and accurately controlled by use of removable spacers. Enclosed construction results in minimum stray electromagnetic interference.

Because of these features, and the resulting wide range of application, the ADL Electromagnet is used in research work requiring:

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Feed Materials Production Center currently under construction. He replaces **James F. Chandler** who resigned the post to rejoin the U. S. Corps of Engineers at Fort Worth, Texas. **J. Perry Morgan** has been appointed manager of the St. Louis Area, responsible for supervising construction and operation of AEC uranium-production plants at Mallinckrodt Chemical Works and elsewhere in the St. Louis vicinity. Dr. Morgan, before his new assignment, directed the work of the staff technical branch of the New York Operations Office Production Division.

E. W. R. Steacie, vice president (scientific) of the National Research Council of Canada since 1950 and director of its division of chemistry since 1939, has been appointed to the NRC presidency. He succeeds **C. J. Mackenzie** who served as NRC president for twelve years and who has been named to head the newly created Crown company, Atomic Energy of Canada, Ltd., which took over operation of the Chalk River atomic-energy project from the NRC on April 1 (NU, Mar. '52, p. 80).

D. G. Calkins has been appointed to head the new radiochemistry department recently organized by Industrial Nucleonics Corp., Columbus, Ohio. He is a member of the radioisotope committee of the American Society for Testing Materials and, before his new assignment, was engaged in radiochemical research at Battelle Memorial Institute and Oak Ridge.

Robert B. Day, Francis B. Harrison, Harvey I. Israel, and **Frank E. Pretzel** have joined the staff of the Los Alamos Scientific Laboratory of the University of California. Dr. Day is working in the Experimental Physics Division, and Dr. Harrison, an engineering physicist, is with the GMX Division. Dr. Israel is a biophysicist, assigned to the Health Division. Dr. Pretzel, a member of the Chemistry and Metallurgy Division, is a physical chemist.

Adair Morrison, former director of the radiology laboratory of division of physics, National Research Council, Ottawa, is now with Arthur D. Little, Inc., Cambridge, Mass.

Isaac D. Welt has been named assistant director of the radioisotope unit at the VA Hospital in Houston, Texas. Formerly with the Public Health Research Institute of the City of New York, Inc., Dr. Welt has also been appointed assistant professor of bio-

HOW TO SOLUBILIZE RADIOACTIVE PARTICLES

There are few effective ways to remove radioactive contamination. One is to solubilize the offending material and rinse it away with large quantities of water. Another is to remove the soil by detergent action. Neither method is entirely satisfactory.

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chemistry at Baylor University's College of Medicine.

James McCormack, Jr., director of the AEC's military applications division from 1947–51, has been appointed director of nuclear applications of the Office of the Deputy for Development, Headquarters, Air Research and Development Command.

Sherman Naymark, has been named chief of the naval reactor division of the AEC's Schenectady, N. Y., Operations Office. Commander Naymark was associate director of naval reactor work at Argonne National Laboratory prior to the Schenectady appointment.

Glenn Murphy will head the department of aeronautical engineering at Iowa State College and at the same time continue his work as senior engineer at the college's Institute for Atomic Research.

J. D. Graves, former assistant chief of the physics branch of the Naval Radiological Defense Laboratory, has been named to the radiation engineering staff of Stanford Research Institute, Stanford, Calif.

MEETINGS

Conference on Nuclear Energy (Atomic Energy and the Future)—Michigan State College, East Lansing, Mich., May 20–21

American Society of X-Ray Technicians, Annual Meeting—Morrison Hotel, Chicago, Ill., May 25–29

14th International Convention on the Generation and Transmission of Electrical Energy at Very High Voltages—Paris, France, May 29–June 9

American Radium Society, Annual Meeting—Hotel Stevens, Chicago, Ill., June 8–10

Symposium on Molecular Structure and Spectroscopy—Ohio State University, Columbus, Ohio, June 9–13

3d Annual Conference on Industrial Research—Columbia University, New York, June 9–13

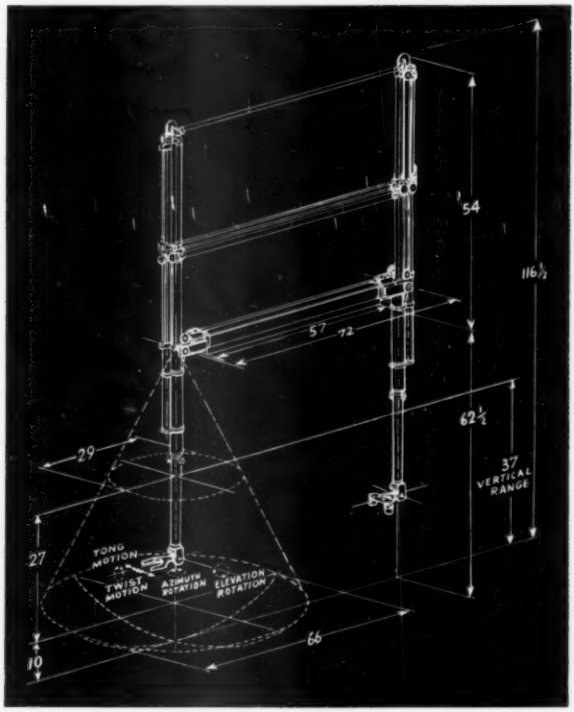
Symposium on Electron Transfer and Isotopic Reactions (sponsored by American Chemical Society and the American Physical Society)—University of Notre Dame, Notre Dame, Ind., June 11–13

American Association of Physics Teachers (meeting in conjunction with Colloquium of College Physicists)—State University of Iowa, Iowa City, Iowa, June 11–14

Conference on Use of Isotopes in Plant and Animal Research—Kansas State College, Manhattan, Kan., June 12–14

5th Applied Mathematics Symposium (American Mathematical Society)—Carnegie Institute of Technology, Pittsburgh, Pa., June 16–17

15th Congress of the Organization for the Advancement of Spectrographic Methods—1 Place Saint Thomas D'Aquin, Paris, France, June 18–20



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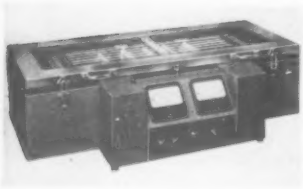
PRODUCTS AND MATERIALS

Crystal Oscillator

General Radio Co., 275 Massachusetts Ave., Cambridge 39, Mass. The type 1213-A crystal oscillator provides standard harmonics of 1 Mc, 100 kc, and 10 kc, with output frequencies up to 1,000 Mc. Short-period stability is said to be 0.0001%. Crystal frequency can be readjusted. The device is designed to be operated from a type 1203-A power supply.

Timer

Nuclear Instrument and Chemical Corp., 229 W. Erie St., Chicago 10, Ill. The model T100 timer is designed to measure elapsed time at intervals of 0.01 min. and will read up to 999.99 min. It will operate with all of the manufacturer's scalers, and with many other scalers as well.



Ionograph

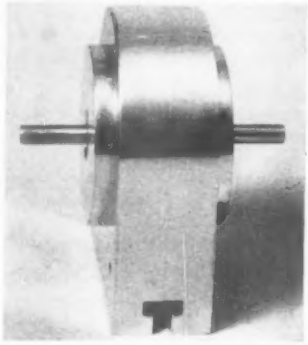
Precision Scientific Co., 3737 W. Cortland St., Chicago 47, Ill. This precision ionograph separates and identifies such materials as amino acids and proteins by means of electrophoresis on filter paper. The instrument can handle seven filter-paper strips of varying length. Potential can be varied from 0 to 2,500 volts, 0–30 ma. Test temperatures can be in the range from room to 0° C; protection against interfering heat effects is provided. Agar bridges prevent *p*H changes at the electrodes from invalidating results.

Scintillation Counter Console

R-C Scientific Instrument Co., 335 Culver Blvd., Playa del Rey, Calif. The model MAX19TC has a wide-angle gamma scintillation counter in the probe arm for use in thyroid uptake, brain tumor, and blood circulation studies where small quantities of gamma emitters are involved. A preset register, together with a binary scaler, gives a predetermined count. Synchronous clocks are automatically stopped when the predetermined count has been reached. Counting rate is read directly from the calibrated dial of the clock. Two clocks give a wide range of counting rate.

Detector Kit

Allied Radio Corp., 833 W. Jackson Blvd., Chicago 7, Ill. After assembly, this portable G-M counter will detect betas and gammas with energies above 0.4 Mev. The tube operates at 1,200 volts, and has a 300-volt plateau with a 5% slope. A neon bulb indicates that the instrument is counting; ear phones may be plugged in.



Gear Trains

Bowmar Instrument Corp., 4214 Leo Rd., Fort Wayne, Ind. These precision gear trains, available in ratios up to 15,000:1, are designed for instrument applications. For applications where various reductions are required at different times, a variety of internal gearing arrangements may be incorporated. Shaft height and diameter are standard for use with conventional laboratory servomechanisms. It is claimed that maximum efficiency, uniform torque, and minimum backlash are obtained by the use of hobbed gears.

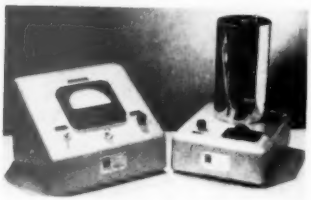
Twin Scaler

Radiation Counter Laboratories, Inc., 5122 W. Grove St., Skokie, Ill. The mark 13, model 6, scaler can be used as two scale-of-16 scalers with separate six-digit recorders, or one scale-of-256 instrument with a single recorder. Each scale-of-16 and its recorder operates independently of the other, and will operate at rates up to 20,000 cpm. Resolving time is said to be 5 μsec. The single voltage supply is variable from 500 to 2,000 volts; it has two regulating circuits so the

voltage to each counter may be set independently of the other. Two timer connections are provided.

Sample Cups

Lovins Engineering Co., 8203 Cedar St., Silver Spring, Md. These sample cups have embossed circular ridges in the bottom, and are designed to prevent creep and maintain accurate geometry of solutions and slurries. The cups are 1 in. in diameter and $\frac{1}{8}$ in. high. They are available in copper, minimum density 150 mg/cm², and stainless steel, about 0.005 in. thick.

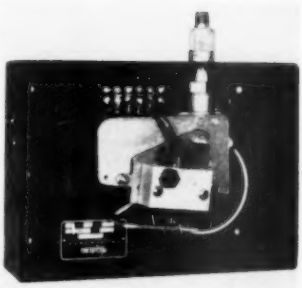


Gammometer

Ohmart Corp., 2347 Ferguson Rd., Cincinnati 38, Ohio. The model AH-1 gammometer is designed to measure gamma activity. It makes use of a cell in which radioactive energy is converted directly into electrical energy; no high-voltage supply is required. The instrument is available calibrated in ranges of 1, 10, 100, and 1,000 mc, or the same values in mr/hr. Longtime precision is said to be ±1% of full scale, and calibration accuracy ±5%. Individual calibration curves are furnished with each instrument. Solid or liquid samples may be placed directly within the cell, with the result that geometry is essentially 4π. Two other models are available, the AH has ranges of 0.1, 1, 10, and 100 mc or mr/hr, and the AH-2 is designed to accept large solid or liquid samples.

Filter-Paper Counter

Nuclear Measurements Corp., 3339 Central Ave., Indianapolis 5, Ind. The models FPC1 and FPC2 filter-paper counting chambers work interchangeably with the flat-sample chambers in the company's proportional counters. The chambers permit use of filter papers up to 7 × 6 in. for the FPC1, and 7 × 10 in. for the FPC2.



Pressure Transmitter

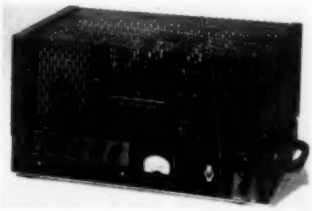
Automatic Temperature Control Co., Inc., 5200 Pulaski Ave., Philadelphia 44, Pa. This Bourdon-tube pressure transmitter operates on the differential-transformer principle. The tip of the tube can be moved by a 0.01-gm force. The motion generates an electric signal proportional to the amount of travel. Accuracy, including linearity and hysteresis effects, is ±0.25% of full range for the ranges from 15 to 5,000 psi; accuracy of the 10,000-psi range is ±1%, it is claimed. All transmitters are equipped with zero adjustment; bleed valves are available where required.

Funnels and Beakers

American Agile Corp., Plastics Division, P. O. Box 168, Bedford, Ohio. These polyethylene funnels and beakers are unbreakable, light in weight, and highly resistant to most corrosive chemicals. The funnels are available from 1 to 12 in. in diameter. Beakers of 250 and 400 ml capacity are available.

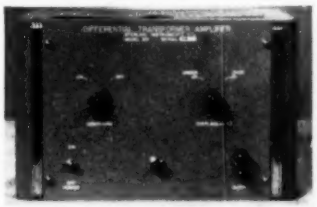
Calibrated Sources

Atomic Instrument Co., 84 Massachusetts Ave., Cambridge 39, Mass. This set contains five beta-emitting calibrated reference sources. The sources are C^{14}, Co^{60}, Tl^{204}, Bi^{210}, and Pa^{234}. The beta energies range from 0.155 to 2.3 Mev. Source strengths, which are specified in each case, are of the order of 10^{-5} mc. A manual showing characteristics and methods of calibration is supplied. Additional mounts and copper disks are provided.



Meter Matcher

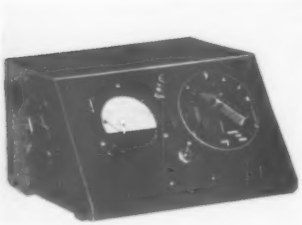
Keithly Instruments, 3868 Carnegie Ave., Cleveland 15, Ohio. The model 105 meter matcher is a power frequency amplifier designed to reduce the errors caused by measuring instruments which load a test circuit. The matcher's input is connected to a test circuit, and its output to a voltmeter or voltage coil of a wattmeter. No more than 150 μa will be drawn from the circuit being tested. Connections for inputs of 15, 75, 150, 300, and 600 volts are provided; in each case the output is 150 volts. Over-all accuracy is said to be such that 0.15% is added to the measurement.



Transformer-Amplifier

Sterling Instruments Co., 13331 Linwood Ave., Detroit 6, Mich. The model 301 differential transformer-amplifier is designed for static and dynamic measurement of displacement, force, vibration, pressure, thickness, etc. The data may be presented on a cathode-ray screen or on direct-writing recorders. Frequency response is from d-c to 1,000 cps, with a range of motion

of the transformer core from ±0.001 in. to ±0.1 in.; the model 302 extends this range to ±1.0 in. The carrier oscillator is self-contained; no external power source is needed for the transducer.



Temperature Controller

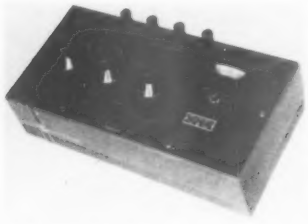
Thermo Electric Manufacturing Co., Dubuque, Iowa. The 500 series Temcometer is a combination of a current input controller and an indicating pyrometer. The device gives stepless control of the power to electric furnaces, ovens, and other heating devices. Any temperature within the capacity of the equipment can be selected and held. The pyrometer is calibrated to 1,000° C; ranges of 427° and 760° C are also available.

Instrument Pen

Minneapolis-Honeywell Regulator Co., Brown Instruments Division, Wayne and Windrim Aves., Philadelphia 44, Pa. The reservoir construction of these pens eliminates flooding by keeping the ink level below the writing tip. The pressure of the pen on the paper is low, which reduces fiber choking; cleaning is made easy by simple disassembly. The device fits on standard recording-instrument pen carriages.

Voltmeter

Southwestern Industrial Electronics Co., 2831 Post Oak Rd., Houston 19, Texas. The model R vacuum-tube voltmeter is designed to measure d-c and a-c volts, and ohms. For measuring voltages, the meter has full-scale ranges from 1 to 1,000 volts, or 1 to 1,000 mv; a distended d-c range indicates 1% of measured voltage, full scale. For resistance measurements, the multiplication factors range from 1 to 10^6; a distended range reads the bottom half of the ohms scale full scale. A standard cell is built in for calibration checking. The d-c amplifier will drive a 1-ma recorder, has a gain of 200, and a range of 0–100 kc.



Voltage Divider

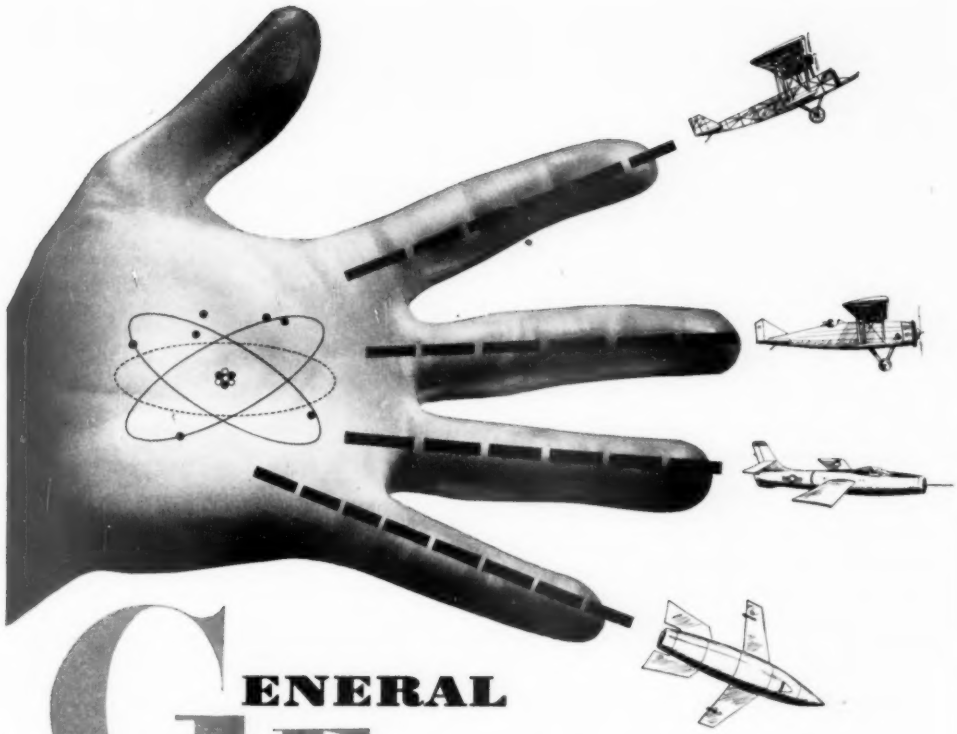
Leeds and Northrup Co., 4934 Stenton Ave., Philadelphia 44, Pa. The model DM4395 voltage divider has three ratio dials, adjustable in fixed steps of $9 \times 10{,}000$, $9 \times 1{,}000$, and 9×100. There is a continuously adjustable ratio slidewire, calibrated from 0 to 100, with half divisions indicated. Accuracy is said to be ±1 main-slidewire division. There are three sensitivity control keys for the external galvanometer. The instrument will handle inputs up to 200 volts, d-c.

G-M Counter

Precision Radiation Instruments, 4113 W. Jefferson Blvd., Los Angeles 16, Calif. The model 107 portable G-M counter is designed for civil defense needs. It has ranges of 0.2, 2.0, and 20 mr/hr; accuracy is said to be 10% on all ranges. A calibration control is provided. The directional probe has a sliding shield for discriminating between betas and gammas. Also available is a mica-end-window tube for detection of alphas as low as 2 Mev, and betas as low as 0.015 Mev.

Burette

Hagan Corp., 323 Fourth Ave., Pittsburgh, Pa. This burette unit has a polyethylene reservoir. To fill the automatic self-leveling burette, the



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- Mechanical Development
- Nuclear Controls

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GENERAL ELECTRIC
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- ★ Low thermal conductivity
- ★ Fiber diameter .00020-.00040 in.
- ★ Specific heat .19
- ★ Thickness .14-.15 in.
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TEXAS, OKLA. & KANSAS: Thompson Engineering Service, 708 Hemphill St., Fort Worth 4, Texas. Fairmont 5340

MIDWEST: Burnie L. Weddle, 3218 West 29th St., Indianapolis 22, Ind. Hickory 8685

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THE H. I. THOMPSON COMPANY
1741 CORDOVA STREET
LOS ANGELES 7, CALIF.

operator squeezes the reservoir. The reservoir is resistant to chemical attack, and will not contaminate standard titrating solutions. The units are available in 10 and 25-ml sizes, graduated to tenths of a milliliter.

Resistance-Limit Bridge

General Radio Co., 275 Massachusetts Ave., Cambridge 39, Mass. Percentage deviation of unknown resistors can be determined with the type 1652-A bridge. External or internal standards may be used; the internal standard is adjustable from 1 to 1,111,-111 ohms, in steps of 1 ohm. Maximum deviation is ±20%, and accuracy is 0.5%, it is claimed. The bridge can also be used to match one resistor to another, or as a conventional decade Wheatstone bridge for null-method measurements.

INDUSTRY NOTES

▶ **Magnex Corp.,** 900-28 Van Wyck Expressway, Jamaica, N. Y., has been formed for the production of nuclear instruments, transformers, relays, and other electronic equipment. The company is the production affiliate of Patterson, Moos and Co., New York, N. Y. Controlling interest in Magnex is held by Nathan Straus-Duparquet, Inc., New York, N. Y.

▶ **American Agile Corp.,** Box 168, Bedford, Ohio, has announced the completion of its new building at 5461 Dunham Rd., Maple Heights, Ohio. The 12,500-ft² building will be used for production of the company's corrosion resistant equipment.

▶ **Nucleonic and Radiological Developments Ltd.** has moved into new quarters at 22 Marshgate Lane, London, E15, England. The bigger premises will provide room for a projected expansion of the scope of activities.

▶ **Polytechnic Research and Development Co., Inc.,** 55 Johnson St., Brooklyn, N. Y., has made some staff promotions: Harry C. Nelson is now manager of instrument sales; Herbert A.

SANBORN
RECORDING EQUIPMENT

AMPLIFIERS
General Purpose
Strain Gage

RECORDERS
One-, Two-, and Four-Channel

SEPARATELY
or
in COMBINATION

INTERCHANGEABILITY of Preamplifiers and Amplifiers permits recording of many different types of phenomena.

SINGLE-CHANNEL

TWO-CHANNEL

FOUR-CHANNEL

Recording channels in these systems may include EITHER a Strain Gage or General Purpose Amplifier, or the latter in combination (in 2-, and 4-channel systems) with either AC or DC Preamplifiers. For, any of the Amplifiers or Preamplifiers may be quickly REMOVED from its place and as quickly REPLACED with an alternate type.

SANBORN RECORDING SYSTEMS produce permanent records by inkless, heated stylus on plastic coated paper in true rectangular coordinates. Systems available in single-, two-, and four-channel models. Channels operate independently of each other, but record simultaneously. Up to eight paper speeds. Timing and coding.

Write for completely descriptive catalog

SANBORN COMPANY
Cambridge 39
Massachusetts

Finke is director of engineering; and Harmon R. Traver is the new manager of manufacturing. A new sales office has been opened at 737 N. Seward St., Hollywood 38, Calif., under the direction of W. A. C. A. Yearsley.

▶**Kinney Mfg. Co.,** 3529 Washington St., Boston, Mass., has announced that Harold G. Saunders is the company's new sales manager.

LITERATURE AVAILABLE

Radioelements. Catalog B gives complete details on radioelements and accessories. *Eldorado Mining and Refining (1944) Ltd., Box 379, Ottawa, Canada.*

Instruments. Condensed catalog gives data and prices of nucleonic instruments and accessories. *El-Tronics Inc., 2647 N. Howard St., Philadelphia 33, Pa.*

Resistors. Bulletins B-6 and B-7 describe boron-carbon and deposited-carbon half-watt resistors. *International Resistance Co., 401 N. Broad St., Philadelphia 8, Pa.*

Isotopes. Catalog gives complete data on pile-produced isotopes. *Eldorado Mining and Refining (1944) Ltd., Box 379, Ottawa, Canada.*

Pickups. Illustrated bulletin CED-1503 describes vibration and acceleration pickups. *Consolidated Engineering Corp., 300 N. Sierra Madre Villa, Pasadena 8, Calif.*

Beta gage. Bulletin R-52 illustrates gage for industrial control. *Industrial Nucleonics Corp., 1205 Chesapeake Ave., Columbus 12, Ohio.*

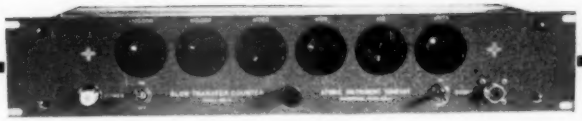
Magnet wire. Bulletins 402G and 403C describe properties of high-temperature magnet wires. *Sprague Electric Co., North Adams, Mass.*

Variable resistors. Catalog 70 gives data on variable resistors. *Chicago Telephone Supply Corp., Elkhart, Ind.*

Valve. Bulletin AVX-310 describes explosion-proof air-control valve. *The Bellows Co., 230 W. Market St., Akron, Ohio.*

Drives. Technical data sheet M1 describes combination fixed and variable speed drives. *Metron Instrument Co., 432 Lincoln St., Denver 9, Colo.*

Printed circuits. Bulletin 1151 gives data on standard circuits available. *Stupakoff Ceramic and Mfg. Co., Latrobe, Pa.*



A new approach to electronic counting

ATOMIC'S
GLOW TRANSFER COUNTER

Here is an entirely new concept in counting, using the cold cathode glow (Etelco, Ltd.) transfer tube. Atomic's Model 162 can be utilized as a counter; as a rapid push-button re-settable register; or as a slow scaler. When two units are run in cascade, one feeds millions into the other.

- Maximum capacity, 1,000,000 counts
- Speed, zero to 2000 cps
- All counting, indicating, and transfer done with glow transfer (Etelco, Ltd.) tube
- Bright red neon glows (not lights) show accumulations up to million

By adjustments provided, Model 162 accepts positive or negative pulses which exceed 5 to 75 volts, depending on control setting.

Input jack and remote jack for special preamp or external re-set.

Input impedance .01 mfd in series with 1.0 megohms.

Exclusive American Agent for Ericcson (Etelco, Ltd.) glow transfer tubes upon which this counter is based. Tubes stocked in Cambridge, Mass. Write for prices.

ATOMIC INSTRUMENT COMPANY
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Outstanding amongst these are high melting point, low coefficient of expansion and ability to withstand large and rapid temperature changes, superior electrical insulation qualities, chemical inertness and transparency.

COOPER HEWITT ELECTRIC COMPANY
Dept. E, 721 Grand Street
Hoboken, N. J.

Cooper Hewitt

LETTERS

Functional Classification of Personal Dosimeters

DEAR SIR:

Personal dosimeters, for measuring the cumulative dose of X- or gamma radiation received by individuals, are often classified according to the type of detector used, e.g., ion chamber, photographic film, color-changing liquid, etc.* Occasionally they are classified according to the extent to which they are instant-reading, or the dosage range covered, or the requirement for auxiliary readers.†

A classification by *function* is easily made if it is recognized that personal dosimeters are usually intended for use in either of two general types of situations, as for example:

Situation A: A worker, equipped with a personal dosimeter, must enter an area he knows to be radioactive. By consulting his dosimeter at frequent intervals, he knows what his cumulative dose is at the moment and can tell when to quit the area to avoid exceeding maximum permissible dose.

Situation B: Atomic war threatens some large area and personal dosimeters are issued to all persons in the area. When and if atomic war breaks out, the majority of these persons find themselves far from the scenes of trouble and their dosimeters remain unused. Some less fortunate individuals are within range of an atomic burst; they receive appreciable doses of gamma radiation, and their dosimeters are later read with "after-the-fact" interest.

The device used in Situation A might be called a *counseling dosimeter* since its prime function is to provide continuous information or counsel as to the wearer's dose. The name *early warning dosimeter* may be adequate in some situations, but the typical counseling dosimeter is not a true warning device. It has no alarm to sound, no light to flash. Moreover, it performs functions which a mere warning device does not perform: It shows at all times the actual value of dose, whether negligible, borderline, or excessive.

The device used in Situation B might be called a *completion dosimeter* since it does not provide continuous service but merely tells you—at the completion of some period of interest—what the dose has been. The name *casualty dosimeter*, although useful in some instances, is not generally applicable. Its proper meaning is a high-range device; but not all high-range devices are of completion type, and not all completion devices have high range. In any event, the name *casualty dosimeter* is unfortunate in that it implies that the dosimeter is to be used only by casualties or persons likely to become casualties.

One might suppose that the terms "instant-reading" and "noninstant-reading" make the terms "counseling" and "completion" superfluous. It is easily shown, however, that the two sets of terms do not correspond. There are some dosimeters which are instant-reading but are not of counseling type (the self-developing film badge, for example).

According to the proposed functional classification scheme, some of the existing types of personal dosimeters are to be classified as tabulated below:

PERSONAL DOSIMETERS—Proposed Classifications

COUNSELING TYPE:
- Ion chamber with a fiber or needle indicator
- Film badge of self-developing type (packet containing several units)
- Color changing liquid, if of low range
- Color changing crystal, if of low range

COMPLETION TYPE:
- Ion chamber without indicator
- Film badge of conventional type
- Film badge of self-developing type (single unit)
- Color changing liquid, high range only
- Color changing crystal, high range only
- Radiophotoluminescent glass

A civil-defense worker might, of course, carry both a counseling dosimeter and a completion dosimeter (as well as a dosage-rate meter of some sort). The counseling device would provide on-the-spot information on the dose received so far, whereas the completion device would provide a permanent record of total over-all dose.

A typical counseling device might cover the range from 0 to 20 r, a typical completion device from 0 to 600 r.

A counseling device might cost $5 to $50, whereas a completion device might cost only $1. (It might prove feasible to incorporate a small completion device in each counseling device.)

It is hoped that persons interested in comparing the diverse types of personal dosimeters currently being developed will find the proposed functional classification to be a helpful one.

WILLIAM A. SHURCLIFF
Research Department, Polaroid Corporation
Cambridge, Massachusetts

* D. Taylor, *J. Sci. Instr.* **27**, 81 (1950); D. E. Gray, J. H. Martens, "Radiation Monitoring in Atomic Defense" (D. Van Nostrand Company, Inc., New York, 1951).

† Such classifications were proposed by Subcommittee 7, Radio-Television Manufacturers Assn., March 3, 1952, New York.

Binary vs Decade Scalers

DEAR SIR:

The February, 1952, issue of NUCLEONICS contains, on page 82, a Letter to the Editor by R. R. Newell on the topic "Binary vs Decade Scalers." He has stated the case for binary scalers very well in pointing out (1) the advantage of counting for a fixed number of counts to obtain uniform statistics, and (2) that the more reliable binary scalers are no less convenient than decade scalers for fixed-count work.

We further favor fixed counting because it is much simpler to adapt to automatic equipment which records the time for a given number of counts, as contrasted to recording the number of counts during a fixed interval of time. We use automatic equipment whenever possible because it speeds up the taking of data and reduces the chance of operator errors.

With regard to Dr. Newell's second point, we would like to add that binary scalers are actually more convenient for fixed-count work. Although one would prefer to obtain a large number of counts at each point, there is always a compromise with the amount of time that one can afford to spend in obtaining the count. With binary scalers the number of counts can be changed by a factor of two, with decade scalers one must change by a factor of ten. We feel that this is a very cogent reason for employing binary scalers in all fixed-count work. We also prefer them in fixed-time work, because of their greater reliability.

W. H. JORDAN
P. R. BELL
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Every Top Management Man... In Every Industry

SHOULD BE ABLE TO ANSWER THESE QUESTIONS ABOUT A MOST CRITICAL EMERGENCY IN OUR COUNTRY'S AFFAIRS

Q. Why is iron and steel *scrap* a matter of importance to me?

A. Steel for our country's military program and civilian economy is being produced at the annual rate of 107,000,000 tons in 1951 . . . 119,500,000 tons expected in 1952. Steel-making capacity is being increased now to meet those quotas.

What Do I Get For My Scrap?

In addition to being paid for your scrap, you remove nuisance inventory from your plant—saving valuable floor space. Also, you have a better chance of *getting* new steel or steel products. But, *most important*—you help alleviate a dangerous condition threatening our country's capacity to rearm and satisfy civilian requirements at the same time.

Q. How does scrap figure in the production of steel?

A. Steel is composed, generally speaking, 50% of pig iron, 25% of "production" scrap (that is, the scrap which is produced as a by-product of steel-making) and 25% of "purchased" scrap.

Q. Is scrap getting scarce?

A. Yes. The supply of *purchased* scrap is not increasing fast enough to meet the needs of increasing steel production.

Q. What if the needed scrap isn't obtained?

A. Open-hearth furnaces will not be able to operate at capacity. That will mean a loss of steel production . . . and fewer products made of steel.

Q. Why not use pig iron instead of scrap?

A. Every ton of scrap conserves approximately 2 tons of iron ore, 1 ton of coal, nearly ½ ton of limestone and many other vital natural resources—to say nothing of the extra transportation facilities that would be otherwise required.

Q. How can *more* scrap be furnished?

A. By everybody pitching in—as we always do in every emergency—and searching out all possible sources of scrap.

Q. What are these sources?

A. Metal-fabricating plants normally turn over to scrap dealers the scrap left from machining. But there's not enough of this to fill our present enormous need. So everybody—both in and out of the metal-fabricating industries—must sell scrap in the form of *idle metal*.

Every pound of idle metal is needed to keep our steel mills operating at top capacity. Sell your idle metal to a local scrap dealer right away.

What Do I Do *First*?

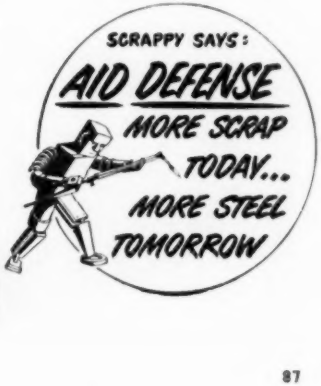
Write for free booklet. It tells how to set up a Scrap Salvage Program in your plant. Thousands of plants are cooperating. Do your part now! Address Advertising Council, 25 West 45th Street, New York 19, N. Y.

Q. *We* don't *produce* scrap—how can *we* help?

A. Scrap is any kind of iron and steel that's gathering dust—obsolete machines or structures, jigs and fixtures, pulleys and wheels, chains and track, valves and pipe—*anything* with rust on it or dust on it. Non-ferrous scrap is needed, too.

Q. What do we do with it when we find it?

A. Use your normal channels or get in touch with a recognized scrap dealer.



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Get the advantages of these fluorocarbon plastics—fabricated by U.S.G. The finest dielectrics especially for high frequency service, chemically inert, non-contaminating, non-gassing, zero water absorption, unaffected by humidity, tough, resilient, serviceable from –110°F. to 500°F. without change in critical electrical or physical characteristics. Write for Bulletin No. 300.

*duPont's trademark for its tetrafluoroethylene resin

UNITED STATES GASKET COMPANY
FLUOROCARBON PRODUCTS DIVISION
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INDEX TO ADVERTISERS

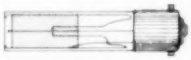
May, 1952

American Phenolic Corp. . . 68
Atomic Instrument Company 85
Berkeley Scientific Corporation 59
Bersworth Chemical Co. . . 78
Central Research Laboratories, Inc. 79
Cole Limited, E. K. 7
Cooper Hewitt Electric Company 85
Distillation Products Industries 75
Eldorado Mining and Refining (1944) Limited . . . 71
El-Tronics, Inc. 3
General Electric Co. 8, 83
International Resistance Company 65
Kinney Manufacturing Co. . 5
Little, Inc., Arthur D. 78
Marion Electrical Instrument Co. 69
Minneapolis-Honeywell Regulator Co. 2
Northrop Aircraft, Inc. 78
Nuclear Instrument & Chemical Corp. . . . . Fourth Cover
Nuclear Research Corp. . . . 77
Pratt & Whitney Aircraft, Div. of United Aircraft Corp. 63
Radiation Counter Laboratories, Inc. . . . . Third Cover
Radioactive Products, Inc. . . 67
Sanborn Company 84
Sorensen and Company . . . 4
Thompson Company, H. I. . 84
Tracerlab, Inc. 6
United States Gasket Company 88
Victoreen Instrument Co. Second Cover
Weston Electrical Instrument Corp. 70

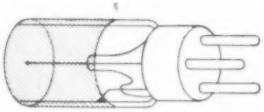
This index is published as a convenience to the readers. Every care is taken to make it accurate, but NUCLEONICS assumes no responsibility for errors or omissions.

RCL Precision Micro Geiger Counters

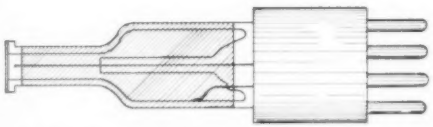
Radiation Counter Laboratories, Inc., *are pleased to present the following special designs for those scientists interested in small counters with low background* ***(illustrations are actual size):***



RCL 7 mm Mica Window Counter, Bayonet base, Mark 1 Model 107, **$95.00.** Connecting cable to your scale, **$25.00 extra.**



RCL 16 mm Mica Window Counter, Standard 3-prong base, Mark 1 Model 106, **$75.00.** Connecting cable to your scaler, **$19.50 extra.**

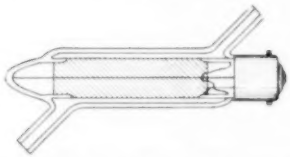


RCL Miniature End Window Search Counter, Standard 4-prong base, Mark 1 Model 105, **$65.00.** Connecting cable to your scaler, **$19.50 extra.**

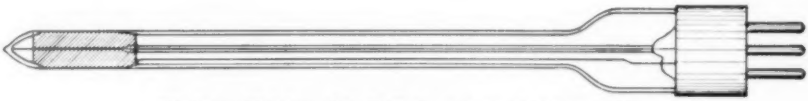
RCL 5 mm Thin Wall Beta Counter, Miniature Bayonet base, Mark 1 Model 101, **$99.00.** Connecting cable to your scaler, **$29.50 extra.**

RCL 7 mm Thick Wall Gamma Counter, Bayonet base, Mark 1 Model 110, **$65.00.** Connecting cable to your scaler, **$25.00 extra.**

RCL 7 mm Thin Wall Beta Counter, Bayonet base, Mark 1 Model 102, **$75.00.** Connecting cable to your scaler, **$25.00 extra.**



RCL 7 mm Thin Wall Annulus Counter, Bayonet base, Mark 1 Model 72, **$85.00.** Connecting cable to your scaler, **$25.00 extra.**



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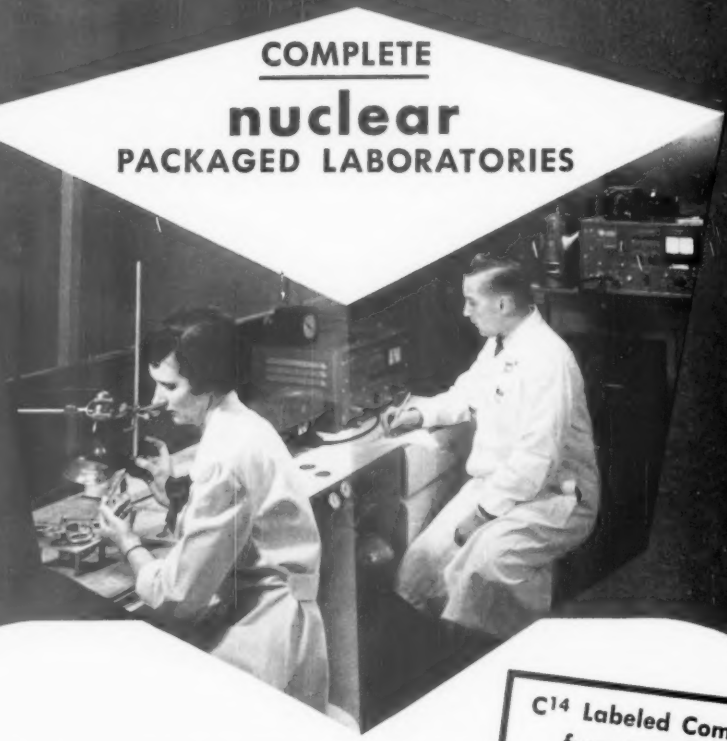

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